Short and Long Terms Strength Performances of Cemented Paste Backfill

E.Yilmaz, A.Kesimal & B.Ercikdi
Department of Mining Engineering. Karadeniz Technical University, Trabzon, Turkey
M.Benzaazoua, T.Belem & B.Bussière
URSTM, University of Quebec in Abitibi-Temiscamingue, Rouyn-Noranda, Quebec, Canada

ABSTRACT: This paper presents the short (up to 28 days) and long (up to 180 days) terms strength gain performances of paste backfill samples prepared with two types of Portland composite cement (types PKC/A and PKC/B) and two mill tailings with different sulphur content (tailing samples Tl and T2). For the selection of an optimum paste backfill mixes at 28 days of curing, four binder contents ranging between 4 and 7 wt% were used. The end results showed that paste cylinders with a binder content of 6 and 7 wt% produced maximum unconfined compressive strength values of 0.8 and 0.9 MPa, respectively. Moreover, 7 wt% of binder content was used to evaluate the effects of binder and tailing types on the long term strength performance of cemented paste backfill. As a result, the strength development of paste cylinders with PKC/A binder has shown a 13% higher compressive strength than that of the PKC/B binder. For a given binder type, the hydration process seems to be directly related to the tailings composition and the binder content.

1 INTRODUCTION

Mine backfilling is of great importance to provide a safe working environment in underground mine openings and to prevent and/or minimize subsidence occurring on surface (Thomas *et al.* 1979; Stone, 1993; Brackebusch, 1995; Hassani and Archibald, 1998; Grice, 1998). The underground mine openings created by the ore stoping are backfilled using a cemented tailing paste in order to provide ground support for the surrounding mine structures and/or a disposal site for sulphide tailings. The paste backfill becomes increasingly widespread world-wide. The possibility of placing underground up to 60% of the produced tailings and reducing significantly the tailings disposal and rehabilitation costs are important advantages of the paste backfill. As a matter of fact, the tailings containing sulphide are unstable in the presence of air and water by generating acid mine drainage.

Paste backfill can be defined as a high density material that consists of mixing humid fine tailings, hydraulic binder composed of one and/or more cement reagents with a proportion ranging between 3 and 7wt%, and mixing water to set a solid content ranging from 70 to 80 wt% depending on the desired consistency. The main role of binders used in paste backfill is to produce the needed mechanical resistance. Each of paste backfill components plays greatly an important role during its transportation, placement and strength gain at short and long terms (Brackebusch, 1995; Beleme/*al.,* 2001;Benzaazoua *et al.* 2002; Kesimal *et al.* 2002a, b; Yilmaz, 2003; Yilmaz *et al.* 2004a, b; Fall *et al.* 2005).

Some problems in the short and long terms performances of paste backfill are encountered in some cases of sulphide rich mill tailings. It is also well known that deterioration of construction works occurs when they are subjected to the waters containing sulphate or acid. In the case of paste backfill the oxidation of existing sulphide minerals, such as pyrite and pyrrhotite, in the presence of oxygen and water may lead to the formation of acid and sulphate and to the undesired chemical reactions (called sulphate attack) with the components of the backfill. The sulphate attack could results in the loss of the fill stability and eventually the collapse of the backfill with the concomitant losses in workforce and halt in ore production (Benzaazoua *et al.* 1999; Berniere/a£ 1999).

Many researches have shown that the strength acquisition of the paste backfill depends on the characteristics of binder, tailing and mixing water, and their proportion used in mixture (Lamos and Clark, 1989; Quellet *et al.* 1998; Bernier *et al.* 1999;

Belem et al 2000, Ereıkdı *et al* 2003, Yılmaz *et al* 2003, Kesımal *et al* 2003, Benzaazoua *et al* 2004) The purpose of this paper ıs to investigate the short and long terms strength gaming of paste cylinders prepared from various binder types and proportion To reach this aim, mill tailings from a Turkish hard-rock mine were sampled (tailing samples Tl and T2) for the preparation of various paste mixtures The short term strength gain was investigated through the analysis of the effects of binder types and their proportion used with the mill tailings Tl and T2 at 3, 7 and 28 days of curing periods The long term strength gam was studied through the analysis of the effects of binder types used with tailing samples Tl and T2 after curing times of 3, 7, 28, 90 and 180-day using a binder content of 7% by dry weight

2 MATERIAL AND METHOD

2.1 Material

2 11 Sampling

Two types of sulphide mine tailings (samples Tl and T2) from a high grade copper-zmc underground mine in northeast of Turkey are sampled for the preparation of various paste backfill mixtures These samples are taken as representative of the tailings streams after having been filtered at the paste backfill plant The solid concentration of the tailings is ranged between 74 and 84% Tailing samples Tl and T2 have a sulphur content of 47% and 34%, respectively Mam physical properties of the both mine tailings are presented in Table 1

Table 1 Physical properties of mill tailings Tl and T2

Property	Tl	T2
Specific gravity (g/cm^3)	4 67	4 40
Specific surface area (m^2/g)	175	2 65
Dio *(pm)* grain size at 10% passing	0 80	0 81
D_{20}(fun) gram size at 20% passing	2 50	3 00
DjoOtm) grain size at 30% passing	7 00	6 00
D_M *(urn),* gram size at 50% passing	18 50	17 00
D_{60} ()im), gram size at 60% passing	26 50	25 00
DM (Jim), gram size at 90% passing	66 00	75 00
Cu", coefficient of uniformity	33 13	3125
C_c", coefficient of curvature	2 31	180
U*", uniformity	2 98	4 36

* <D_{60}/D_{10}) " KD_{30})^2 / (Dso $D_{,0}$)], "* [(D,o-D,o)/ (D_{s0}]

The gram size distribution of the tailing material was obtained by using a Malvern Mastersizer® particle size analyser under humid conditions Tailing sample Tl was found to have approximately 52 wt% of 20 *ßm* particles and tailing sample T2 have approximately 54 wt% of 20 /im particles, which indicates that both mill tailings can be classified as a medium size tailings according to Kesımal *et al* (2002b) These types of tailing material usually good paste backfill, but typically have lower strength than the coarse tailings because of a higher water-to-cement ratio needed for reaching the target consistency (Landnault, 2001)

2 12 Binders

In this study, the Turkish Portland composite cements (PKC), namely, PKC/A 32 5-R (type A) and PKC/B 32 5-R (type B) were used The PKC/A binder is got from milling 94-80 parts of Portland cement clinker together with a corresponding amount of two kinds of additives (6-20 parts) and a quantity of gypsum The PKC/B binder is got from milling 79-65 parts of Portland cement clinker and a corresponding amount of two kinds of additives (21-35 parts) as well as a quantity of gypsum Each of these cements was manufactured in compliance with the TS 12143 standard The chemical properties and compressive strengths of the binders are listed m Table 2

Table 2 Properties of binder types used (Ünye Çimento Sanayi A S)

Elements	PKC/A 32 5-R (%	PKC/B 32 5-R(%)
$Si0_2$	19 12	28 03
AI2O3	7 01	8 21
Fe_20_3	2 68	3 42
CaO	42 50	32 60
MgO	108	148
SO3	196	153
Free CaO	0 55	0 23
Insoluble residue	1160	15 06
Soluble SIO2	9 72	5 83
Loss on ignition	208	2 65
Undetermined	170	0 96
Total	10000	100 00
Unconfined compressive strength (MPa)		
1day	9 2	6 3
2 day	16 7	122
7 day	33 8	23 9
28 day	44 1	35 3

2 13 Preparation of mixtures

In this study, two different mixture recipes were prepared to better understand the strength gain of the paste backfill after short and long terms curing times Table 3 presents the laboratory tests program for the relevant mill tailings at short and long terms curing times The best slump for these tailings was established to 7" (Kesimal *et al* 2004) In the present study, however, the effect of the slump on the paste backfill performance was not investigated

Tap water was used as mixing water during the preparation of the paste backfill samples Water-to-cement ratios for the mix with solid concentration of 82% and using binder proportions of 4, 5, 6 and 7 wt% are 5 7, 4 6, 3 9 and 3 4, respectively Water-to-cement for the mix with solid concentration of 77% and using binder proportions of 4, 5, 6 and 7 wt% are 7 8, 6 3, 5 3 and 4 6, respectively

The prepared paste samples were cast into plastic cylinders (having 10 cm diameter and 20 cm height) and a ratio of height to diameter of 2 A total of 204 paste backfill samples were then cured in humidity chamber at approximately 75% for short and long terms curing in order to simulate the underground mine conditions

2.2 Mechanical testing

In the present study, the short and long terms strength acquisition of paste backfill samples were investigated through the unconfmed compression tests on a total of 204 paste cylinders to determine their unconfmed compressive strength (UCS)

The UCS values were used to select an optimum mixture recipe for each of tailing types The compression tests were performed by using an ELE Multiplex 5 0 digital mechanical testing equipment having a normal load capacity of 50 kN and a displacement speed of 1 mm per minute

3 RESULTS AND DISCUSSION

3.1 Effect of the binder type and proportion at short term

In the mine backfilling operations, a slight reduction in the binder content leads to a substantial cost saving Therefore, it is important to perform a series of tests using different paste backfill mix, to study the effect of binder content on the strength gam of the paste backfill In this study, the UCS values were obtained from averaging the UCS of three test samples for each binder content and curing time

Figs 1 and 2 show the relationship between the UCS and curing time for paste backfill samples As expected, binder type and content play a direct role on the strength gaming of the paste backfill samples As shown in Fig la, the strength acquisition of the paste backfill with PKC/A binder is always proportional to the binder contents The strength gam of the paste backfill samples increases with curing time At curing time of 3-and 7-day, the strength development of the paste cylinders is similar for 4, 5 and 6 wt% binder contents After 28 day of curing time, paste backfill mixtures with PKC/A binder having binder content of 7 wt% reached the maximum UCS value of 1 1 MPa Fig lb shows that the UCS values of the paste backfill samples prepared using PKC/B binder with 4 and 5 wt% are 0 4 and 0 5 MPa, respectively However, these values for paste backfill produced with a binder content of 6 and 7wt% are 0 8 and 0 9 MPa (these values are almost twice than previous ones), respectively

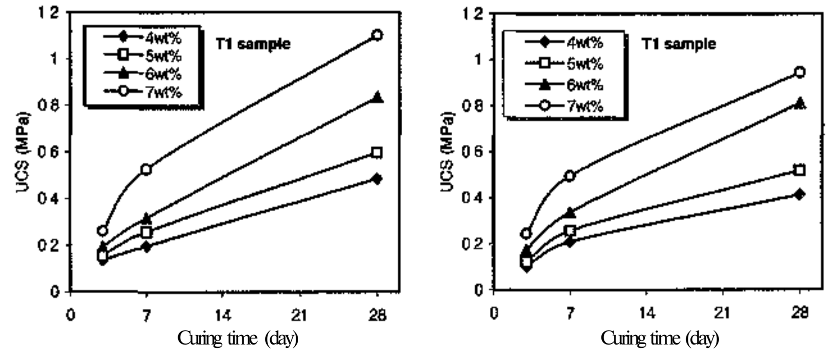
Table 3 Laboratory paste backfill testing program for the studied mill tailings

Short term unconfmed compressive strength tests

Paste backfill samples (Total of 144 samples)	Slump (inch)	Slump (cm)	Binder content (wt %)	Solid content Cw(%)	Water/solid ratio	Cunng time (days) 3	7	28
Tailing Tl with PKC/A binder	7	178	4, 5, 6, 7	82	0 22	12	12	12
Tailing Tl with PKC/B binder	7	17 8	4, 5, 6, 7	82	0 22	12	12	12
Taihng T2 with PKC/A binder	7	17 8	4, 5, 6, 7	77	0 30	12	12	12
Tailing T2 with PKC/B binder	7	17 8	4, 5, 6, 7	77	0 30	12	12	12

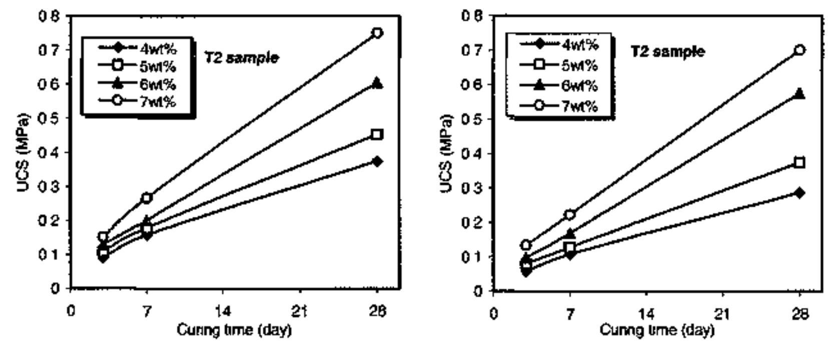
Long term unconfmed compressive strength tests

Paste backfill samples (Total of 60 samples)	Slump (inch)	Slump (cm)	Binder content (wt%)	Solid content Cw (%)	Water/solid ratio	Cunng time (days) 3	7	28	90	180
Tailing Tl with PKC/A binder	7	178	7	82	0 22	3	3	3	3	3
Taihng Tl with PKC/B binder	7	17 8	7	82	0 22	3	3	3	3	3
Taihng T2 with PKC/A binder	7	17 8	7	77	0 30	3	3	3	3	3
Taihng T2 with PKC/B binder	7	17 8	7	77	0 30	3	3	3	3	3



a) Binder type PKC/A b) Binder type PKC/B

Figure 1 Unconfmed compressive strength versus curing time for the cemented paste backfill samples produced from the tailing Tl using (a) PKC/A binder and (b) PKC/B binder



a) Binder type PKC/A b) Binder type PKC/B

Figure 2 Unconfmed compressive strengm versus curing time for the cemented paste backfill samples produced from me tailing T2 using (a) PKC/A binder and (b) PKC/B binder

As a result, for a given binder type and proportion, these differences concern both the strength value of paste backfill samples and the effect of the binder percentage Moreover, from the short term UCS values, paste backfill samples with PKC/A binder were found to have a better performance m comparison to paste backfill samples with PKC/B binder This may be attributed to the composition of PKC/A binder that contains much more natural and/or artificial additives compared to PKC/B binder This observation must be supported by more investigation to verify for the short tenu lower strength value using binder type PKC/B

Fig 2 also showed that the strength increase of paste backfill cylinders for each binder type is proportional with binder content within mixture after 28-day of curing However, the strength gain m the case of binder types used for tailing Tl is slower compared with tailing T2 At 3-and 7-day of curing time, the average strength values of the paste backfill with tailings Tl and T2 is approximately 0 25 and 0 13 MPa, respectively It should be noted that the hydration process is influenced by both the material composition for each tailing type and the binder percentage used in the paste backfill mixtures

Finally, these curves clearly show differences on the strength of each backfill samples For a given binder, these differences m terms of the unconfmed compressive strength are attributed to the chemical and mineralogical composition of each tailing

3.2 Effect of the type of mill tailings at long term

The effect of binder type and proportion on the strength gam of paste backfill made by using mill tailings having different sulphide content was examined for the long term Only a binder content of 7 wt% was tested Fig 3 shows the variation of UCS of the paste backfill made of two different tailings samples m the course of curing time

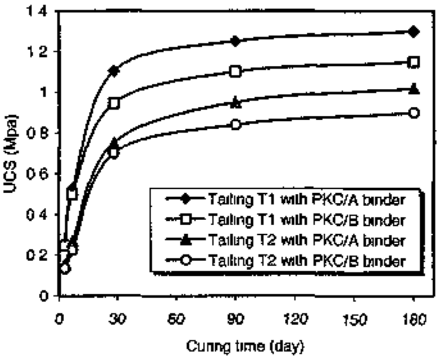


Figure 3 Variation of the UCS of the paste cylinders Tl and T2 using 7 wt% binder in the course of curing time

From Fig 3, it can also be seen that the UCS values of paste backfill samples with tailing sample Tl is always relatively higher than the ones of paste backfill with tailing sample T2 The UCS of paste backfill samples made of tailing sample Tl and binder type PKC/B obtained between 28-and 180-day of curing time provided a better strength gam varying between 20 and 36%, respectively All the paste cylinders with PKC/A binder have a positive effect on the strength acquisition of the samples in comparison with PKC/B binder From the long term tests results, tailing sample Tl produced the higher strength acquisition of around 28% higher than tailing T2 for the same binder percentage

It is well known that sulphide rich mill tailings produce acid m the presence of oxygen and water Sulphide minerals within the cemented composites can oxidize and produce soluble sulphates which can have a negative effect on the paste backfill strength acquisition In most cases, the mechanism of sulphate interaction within the paste backfill acts as three mam stages

- The first stage (stage I) corresponds to a low sulphates (<1000 ppm of SO/) concentration that can lead to an inhibition of hardening process This creates a negative effect on the paste backfill strength gain

- The second stage (stage II) corresponds to a relatively high sulphate concentration (>1000 ppm and <10000 ppm of $S0_4^2$) Precipitation of sulphate can occur and help to the hardening process in parallel with the appearance of hydrated phases such as C-S-H This helps cohesion and positively influence strength of the paste backfill

- The third stage (stage III) happens within already hardened material Sulphate continues to precipitation until no place is available for the precipitation and then expansion occurs (phenomenon called sulphate attack)

In the case studied here, tailings Tl and T2 may involve mechanism of stage II and I, respectively

3.3 **Selection** of **optimum mix**

When paste backfill is used as an underground backfill material for ground support, this material should be investigated in detail from every aspect to ensure strength gam respecting ground support constraints If this is neglected, an unexpected event such as backfill failure in underground mine may take place That event is avoided by mine operators because of the costs and mine safety

Stone (1993) reported that the binder type and content must confer strength of 0 7 MPa after 28-day of curing time (short term) and strength of 1 MPa at 90-day curing time (long term) According to the UCS values obtained in this study, an optimum mixture for tailing samples Tl and T2 after cunng time of 28-day were obtained from paste backfills made with binder proportions of 6 and 7 wt%, respectively Moreover, the target strength values for each tailing sample after 90-and 180-day of curing time (long term) were reached with paste cylinders having a binder content of 7wt%

3.4 Stress-strain behaviour of the paste cylinders

The deformation behaviour of the paste backfill were determined and presented in terms of axial strain (EO and major principal stress (oi) curves

Table 4 Young's modulus and UCS values for 180-day cured samples of the different paste backfill (7 wt% of binder)

	UCS, a. MPa	Young's modulus, MPa			
		Initial Eb	Tangent, E,	Secant, Es	Average E,,,
Tailing Tl with PKC/A binder	1 28	120	200	167	194
Tailing Tl with PKC/B binder	1 12	100	169	127	167
Tailing T2 with PKC/A binder	0 98	67	147	114	141
Tailing T2 with PKC/B binder	0 83	40	111	67	104

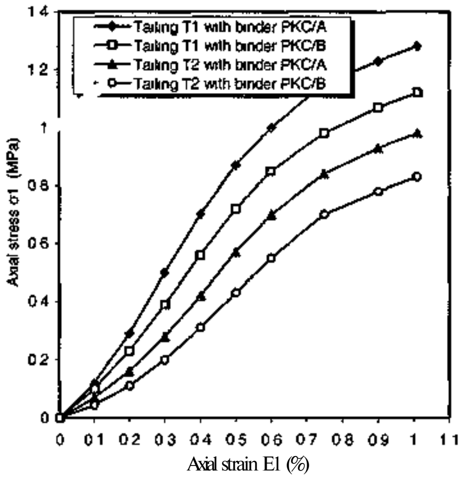


Figure 4 Stress-strain curves of paste backfill with tailing samples Tl and T2 tested after 180-day of curing time

Fig 4 shows the axial stress and strain curves for each of paste cylinders with PKC/A and PKC/B binder types tested after 180 day of curing time Moreover, all of the unconfmed compressive strength values (oi) and Young's modulus (E) of the paste backfill samples derived from the curves of Fig 4 are presented in Table 4 Young's modulus of paste material varies depending on binder type and tailing composition

From Fig 4, it can be seen that the stress-strain behaviour of the samples is elastic-plastic The failure type of the paste backfill samples is a ductile deformation That means paste cylinders never burst under excessive deformation stress such as brittle material Conversely, they may be broken in sample mass, not showing by outside

4 CONCLUSIONS

In this study, a total of 204 of paste backfill cylinders prepared with two different mill tailings (tailing samples Tl and T2) and two binder types (namely, PKC/A and PKC/B) were tested to investigate their short and long terms performances The last results confirm that the strength gain of paste cylinders, for each of tailing samples, is proportional to the binder content The results also showed that the tailing composition depending upon sulphide content and binder types and content has a significant influence on the strength acquisition and hydration process of the paste backfill

From the UCS values, the strength gain of paste cylinders with tailing sample Tl is greater than the one of paste cylinders with tailing sample T2 As a result, the physical, chemical and mmeralogical characteristics of tailing, mixing water and binder to be used in the paste mixture should be investigated in detail To increase the strength of paste backfill samples in the long term rather than in the short term, the tailing composition should be suitable with binder used in the mixture Moreover, the effect of sulphate attack on strength gain at long term should be examined precisely when the paste backfill was produced from sulphide rich tailings To minimize this negative effect, alternative methods (e g the addition of sand and/or lime to the mixture, the use of both sulphate resistant cement and natural and/or artificial additives) should be tried on the samples

5 REFERENCES

Belem, T, Benzaazoua, M, Bussière, B, 2000 Mechanical behaviour of cemented paste backfill Proceedings of the Canadian Geotechnical Society Conference Geotechnical Engineering at the Dawn of the Third Millennium 15-18 October, Montréal, Canada, Vol 1,p 373 380

Belem, T , Bussiere, B , Benzaazoua, M , 2001 The effect of microstructural evolution on the physical properties of paste backfill Proceedings of the 8* Int Conference on Tailings and Mine Waste, A A Balkema, Rotterdam, pp 365-374

Benzaazoua, M , Ouellet, J , Servant, S , Newman, P and Verbürg, R, 1999 Cementitious backfill with high sulfur content physical, chemical and mmeralogical characterization, Cem Cone Res 29 (5), 719-725

Benzaazoua, M , Belem, T , Bussière, B , 2002 Chemical factors that influence the performance of mine sulphidic paste backfill Cem Cone Res 32(7) 1133 1144

Benzaazoua, M, Fall, M, Belem, T, 2004 A contribution to understanding the hardening process of cemented pastefill Mm Eng 17(2)141-152

Bernıer, R L, Li, M G , Moerman, A , 1999 Effects of tailings and binder geochemistry on the physical strength of paste backfill Mining and Environment II, Canada, 1113 1122

Brackebusch, F W, 1995 Basics of paste backfill systems Mm Eng 46(10) 1175 1178

Ercıkdı, B , Kesımal, A , Yılmaz, E , Deveci, H , 2003 Effect of deslımıng on the strength of paste backfill Proceedings of the X Balkan Mineral Processing Congress, Mineral Processing m the 21" Century, Vama, Bulgaria, 15-20 June, pp 850 857

Fall, M., Benzaazoua, M., Ouellet, S., 2005. Experimental characterization of the influence of tailings fineness and density on the quality of cemented paste backfill, Min. Eng. 18(1), 41-44.

Grice, T., 1998. Underground mining with backfill, Proceedings of the second Annual Summit-Mine Tailings Disposal Systems, AusIMM, Brisbane, Australia, p. 14.

Hassanı, F., Archibald, J., 1998. Mine Backfill, CD-Rom, Canadian Institute of Mine, Metallurgy and Petroleum, Montreal, Canada.

Kesimal, A., Alp, I., Yilmaz, E., Ercikdi, B., 2002a. Optimization of test results obtained from different size slumps with varying cement contents for Çayeli Mine's clastic and spec ore tailings. Karadeniz Technical University, Revolving Fund Project Report, Trabzon, 56 pp.

Kesimal, A., Yilmaz, E., Ercikdi, B., Alp, L, Yumlu, M., Özdemir, B., 2002b. Laboratory testing of cemented paste backfill, J.Chamber Min. Eng. Turkey 41 (4), 25-32.

Kesimal, A., Ercikdi, B., Yilmaz, E., 2003. The effect of desliming by sedimentation on paste backfill performance. Min. Eng. 16(10), 1009-1011.

Kesimal, A., Yilmaz, E., Ercikdi, B., 2004. Evaluation of paste backfill test results obtained from different size slumps with varying cement contents for sulphure rich mill tailings. Cem. Cone. Res. 34(10), 1817-1822.

Lamos, A.W., Clark, I.H., 1989. The influence of material composition and sample geometry on the strength of cemented backfill, Hassani et al. (eds.), Innovation in Mining Backfill Technology, Balkema, Rotterdam! 89-94.

Landriault, D., 2001. Backfill in Underground Mining, im W.A. Hustrulid, R.L. Bullock (Eds.), Underground Mining Methods, SME, 2001, pp. 601-614.

Ouellet, J., Benzaazoua, M., Servant, S., 1998. Mechanical, mineralogical and chemical characterisation of paste backfill. Proceedings of the 4th International Conference on Tailings and Mine Waste, A.A. Balkema, 08-11 October, Vail, Colorado, USA, 139-146.

Stone, D.M.R., 1993. The optimization of mix designs for cemented rockfill. In Minefill'93. Proceedings of 5th International Symposium on Mining with Backfill, Jfohannesbourg, South Africa, SAIMM, 249-253.

Thomas, E.G., Nantel, J.H., Notely, K.R., 1979. Fill technology in underground metalliferous mines, International Academic Services Limited, Kingston, Ontario, 1979, 293 pp.

Ünye Çimento Sanayi A.S. Oyak Cement Group, http://www.unyecimento.com.tr/cement.html

Yilmaz, E., 2003. Investigation of the strength characteristics of the cemented paste backfill samples prepared for sulphide-bearing mine tailings, M.Sc. Thesis, Department of Mining Engineering, Karadeniz Technical University, Trabzon, Turkey, H7 p. (in turkish)

Yilmaz, E., Kesimal, A., Ercikdi, B., 2003. Strength properties in varying cement dosages for paste backfill samples. Proceedings of the 10* International Conference on Tailings and Mine Waste, A.A. Balkema^ 12-15 October, Vail, Colorado, USA, 109-114.

Yilmaz, E., Kesimal, A., Ercikdi, B., 2004a. Strength development of paste backfill samples at long term by using two different binders. Proceedings of the 8th International Symposium on Mining with Backfill, The Nonferrous Metals Society of China, Beijing, China, 19-21 September, 281-285.

Yilmaz, E., Kesimal, A., Ercikdi, B,, 2094b. The Effect of material composition on the strength of cemented paste backfill. ROCKMEC'2004, Proceedings of the 7th Regional Rock Mechanics Symposium, Sivas, Turkey, 21-22 Oetober, pp. 123-128. (in turkish)