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Improvement of Environmental Conditions of Faryab Chromite Mine Using Backfill

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ABSTRACT

There are many sources for waste production such as surface & underground mines, mineral processing plant and smelter refinery in Faryab chromite mine which has created serious hazards for environmental conditions. On the other hand, the massive and violent collapse of pillars which has been labelled as a domino failure occurred in this mine. These hazards were led to study the replacement of waste materials in underground spaces. Accordingly, the need for environmental protections and the stability of underground stopes in Faryab mine have necessitated ever stricter requirements for the introduction of a more environmental-friendly mining method which is labelled as green backfill. In this research for estimation of backfill required strength, a numerical model was developed. On the other hand, to reduce or eliminate cement from the backfill mixes, investigations were conducted regarding the replacement of cement by chromite slag for the first time as an alternative. Test results indicated that mechanical properties of backfill materials were improved by chromite slag. The results also showed that cement consumption will be reduced by at least 2-3% using chromite slag as a binding agent. According to these results, it is possible to point out that chromite slag is a potential replacement material for Portland cement in backfill mixes. By using waste materials and chromite slag, the environmental conditions of Faryab mine will improve.

Keywords: Binder agent, Chromite slag, Environmental conditions, Faryab Chromite mine, Green backfill, Stope and Pillar.

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INTRODUCTION

Mining has always been and still is an activity which is essential for development of humankind. This is because a predominant proportion of energy and industrial products is produced from raw materials that are extracted using different mining methods. Although mining activities have a lot of benefits, environmental damages by different reasons such as surface subsidence, water and ground pollution, dust propagation and etc. are perilous aspects of mining activities which in some cases were redounded to shut off mines. In order to abate the environmental impacts of mining operations, much attention is focused on improving the management of mine wastes in recent years. The cost and liability of surface storage facilities for mine waste, whether rock or tailings, have increased significantly. Environmental standards and mine closure requirements are gradually transforming the economics of mine waste disposal.

In the mining industry, with ore extraction a relatively large amount of waste is produced. On the other hand, in most underground mining methods such as room and pillar, stope and pillar and etc., very large spaces are created which may be backfilled with waste materials for improving environmental, economical, safety and stability conditions. The deployed backfilling strategies often make use of the waste rock or tailing that is considered by–products of mining operations. This is an effective means of tailing disposal because it negates the need for constructing large tailing dams at the surface. The backfilling of underground spaces also improves local and regional stability alternatively enabling safer and more efficient mining of surrounding areas (Sivakugan et al., 2006).

There are two basic types of backfilling strategies. The first, uncemented backfilling does not make use of binding agents such as Portland cement. Another, cemented backfilling makes use of a small percentage of binder such as Portland cement, fly ash and etc. (Sivakugan et al., 2006). Since its introduction, cemented backfill has allowed mining companies to increase their ore extraction and improve working and environmental conditions. Although cemented backfill operations have become expensive due to the increasing cost of production and transporting cement to mine sites, it continues to be used. On the other hand, production and use of cement, causes emission of greenhouse gases such as CO2. Mine surveying in Canada shows that only in Ontario province, 700,000 to 840,000 ton CO2 was released as a result of cement consumption in backfill mixes (Desouza et al., 2003). These economic and environmental pressures have led mining companies to carry out researches into the partial or total replacement of cement by other materials. The investigations have shown that most important replaceable materials with cement are fly ash, slag, Waste glasses and gypsum. These materials are generally site specific, readily available and cost-effective relative to cement (Hassani and Archibald, 1998; Petrolito., et. al., 2005).

Reviews have shown that using slag, especially iron and copper, have had a mass effect on cemented backfill mixes properties especially mechanical behaviours such as uniaxial compressive strength (UCS) and young modulus (E). The first tests with iron blast- furnace slag were done during the years 1966-70 in Keretti mine. The tests were continued in the 70's. Regular use of iron slag as a binding agent started in 1978 at Pyhasalmi mine, in 1979 at Vihanti mine, in 1983 at Keretti and at Vammala mine in 1983 (Niemineh and Seppanen (1983)). Thomas and Cowling published the results of their investigations regarding of adding of furnace slag on development of backfill mixes strength at Mount Isa mine in 1978. According to their published results, strength of cemented backfill mixes was developed if slag added as a binder in the range of 4-5 times cement weight (Thomas and Cowling, 1978). Khoek found that the optimum slag/cement content ratio in cemented backfill is 3 in 1981(Khoek (1981)).

Atkinson works showed that the use of copper furnace slag leads to mixes which have a less curing time than cemented backfill mixes. Mount Isa uses copper furnace slag to replace half of the cement in backfill which has saved over 25,000 tonnes of cement annually (Grice (1989)). Benkendorff, investigated the effect of lead and zinc slag on cemented backfill properties. The results showed that this type of slag improves the strength of cemented backfill similar to ordinary Portland cement. The curing time and hardening process were affected by zinc percentage in slag, consequently. So, he mentioned that this is a restrictive element for the replacement of Portland cement by lead & zinc slag (Benkendorff (2006)).

In Faryab mine, there are some resources for environmental pollutants such as tailing and ferro-chromite refinery slag. To improve the environmental conditions, the Faryab Company intended to use them as mine filling materials. Because of the significant distance between mine and cement plant, the above-mentioned slag was used for reducing cement from the backfill mix for the first time. The results show that chromite slag has had a mass effect on mechanical behaviors of cemented backfill mixes.

DEFINITION OF PROBLEM

The Faryab mines are located at 143 km northeast of the town of Bandar- e-Abbas, in the boundary of Kerman and Hormozgan provinces. The Faryab chromite deposit is the main chromite deposit in Iran and one of the known chromite deposits in the entire world. This deposit includes 6 surface and 3 underground mines but operation in open pit mines was ceased some time ago and all activities are concentrated in underground mines (Faryab Co (2007)).

From different underground deposits, the Fetr-6 is the biggest underground mine. Exploration investigations showed that ore reserve in this mine is more than the total reserve of other mines. The ore body of this mine is divided into 3 zones called Phases 1 to 3. To complete the primary mining, stope and pillar method was used as the main mining method of phase 1. Conceptual design and preliminary exploration were carried out in phases 2 & 3, respectively. Figure 1 shows a 3-D view of the Fetr6 ore body (Faryab Co (2007)).

After the first mining was completed in phase 1, the ore extraction rate was recorded as approximately 56%. To achieve higher rate of ore extraction, planning for recovery of remained pillars were done. The use of shotcrete and resin rock bolts had been considered for roof supporting to provide the desired safety level. In spite of these predictions, pillars have had an instability conditions in secondary mining of phase 1. To avoid pillar crushing, some concrete pillars with dimensions of 12 × 4 × 4 m were designed in the layout of mine layout. During construction of the first concrete pillar between remained pillars, some technical and executive problems occurred. Consequently, no improvements were observed in stability conditions of remained pillars. Finally, all pillars were broken which lead to the destruction of 4000 m^2 of the mine. Ground subsidence was observed and mining operations ceased in phase1consequently.

As mentioned above, after this caving occurrence, mining operations in phase1 were ceased and Faryab Company focused on ore extraction from phases 2&3. Since ore thickness in these phases is 20 m, which is more than phase 1, it was necessary to consider a special layout of pillars to avoid caving in these phases.

Because of large amounts of waste materials in the entire mines and instability of hanging wall in phase1, safety and use of waste materials were considered to design phases 2&3. The mining method employed for these phases meant for 100% extraction with complete pillar recovery (Faryab Co (2007)). This mining method includes rib pillar with delayed backfill. Figure 2 shows schematic view of this method. This is a simple, common, low cost and safe mining method integrating mining and backfilling systems. This method was successfully used in Tara mine in Ireland, Cannon, Keretti and Carlin mines in the U.S (www.Tara.infomine.com).

Environmental problems associated with Faryab mine

Waste disposal produced by different activities is a major environmental problem in Faryab mine. Different kind of wastes which produced are as follows:

- Waste rock from surface mines (old mine working)

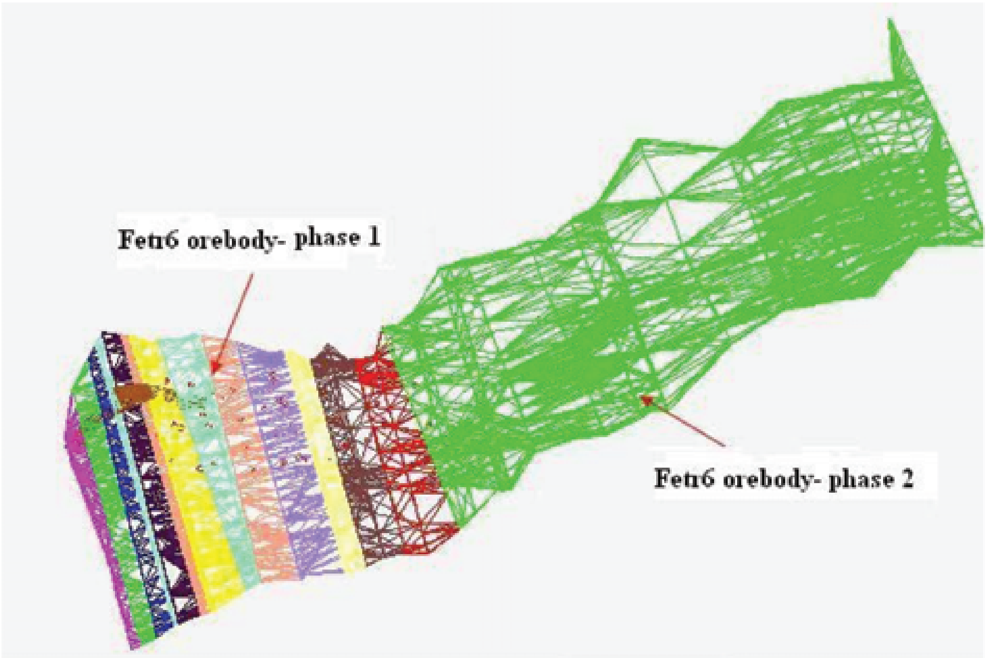

Figure 1. 3-D view of fetr6 ore body wire frame (Faryab Co, 2007)

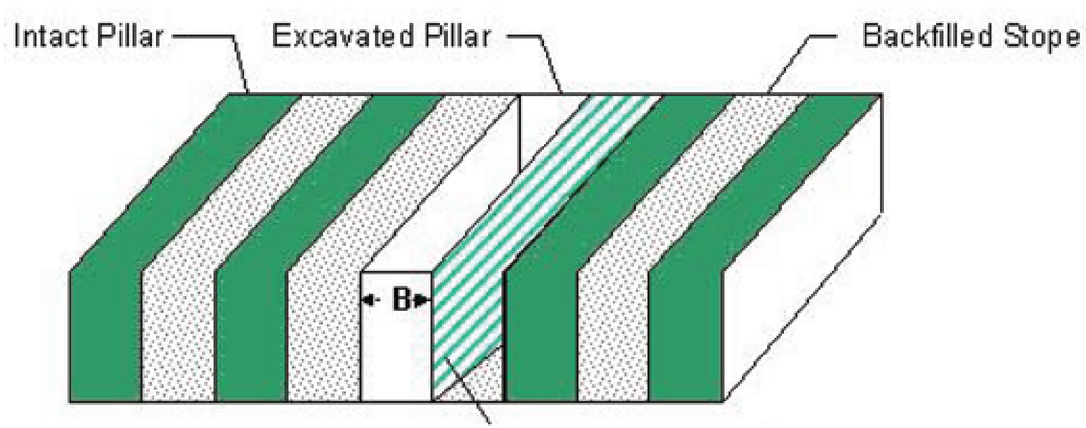

Figure 2. Schematic view of the room and rib pillar mining method with delayed backfill (www.mininglife.com)

- Waste rock from underground developments
- Tailing from washing plant of mine
- Ferro - chromite refinery slag

In Figures 3 to 6 some examples of waste discharge have been shown. Furthermore, in consequence with pillar caving, ground subsidence was observed. This is an irreparable damage for mine environment. No environmental problems happened for the company because the mine, offices and its related plants were not in the vicinity of urban areas and subsidence zone. On the other hand, because all evidence had indicated that all ore bodies could be extracted

Figure 3. Waste discharge of surface mines above the phase 2 of Fetr6 underground mine

Figure 4. Waste discharge of underground mines in valleys of mine region and filling of them

with open pit mining method, based on primary explorations the waste materials from surface mines were dumped at the nearest location from surface pits for economical considerations. After exploration of Fetr-6 deposit, it was found that the waste discharge on this deposit created an artificial overburden with approximately 50-70 m height. Considering unit weight of waste rocks, the 2 MPa additional stresses apply on the phases 2 & 3 sections (Faryab Co (2007)).

Figure 5. Discharge of refinery slag in valleys of mine region and occurrence of instability

Figure 6. Tailing dam and discharge of them along the main road of mine

PROCEDURE OF INVESTIGATIONS

As was shown in Figure 2, in first mining of phases 2 & 3, backfill materials are replaced in excavated rooms. This creates artificial pillars with backfill materials which mean backfill pillars will allow complete pillar recovery in secondary mining of these phases. Thus it is clear that they must be designed for full overburden loading during removal of the intervening secondary stopes in which uniaxial compressive strength of backfill mixes is a critical design factor.

Although there are several methods for the estimation of load of pillar, two most famous ones are tributary area method and numerical modeling. As the average vertical stress values, calculated by the analytical method are usually very close to the maximum value obtained from the numerical model (Peila et al., 2008), a numerical model was developed for estimation of load of pillars. The required strength of backfill materials was calculated by applying an appropriate safety factor to the estimated load of pillar. Also a wide range of laboratory tests were done to determine backfill mixes properties especially mechanical properties. The results have been described as follows:

Field and laboratory investigations

Detailed investigations, both in the laboratory and in situ were carried out to provide reliable data for the numerical analyses. Laboratory investigations were carried out to determine the physical and mechanical properties of the intact rocks including hanging wall, ore body and footwall. To obtain these parameters uniaxial, triaxial and shear strength tests were carried out in accordance with the suggested methods of the International Society for Rock Mechanics- ISRM (Brown (1981)). The test results are summarized in Table 1.

Field investigations were carried out to determine the condition of the rock mass. Geological surveying showed that serpentinisation is the dominant phenomenon in the host rocks. On a global basis, the geomechanical conditions of the rock mass are generally poor. According to the Bieniawski rock mass classification (Bieniawski (1989)), the calculated rock mass rating (RMR) value and the GSI index are estimated at 45 and 40, respectively, for all the types of rock masses found here. Note that although the intact rock properties of host rocks have meaningful differences with the ore body (Table 1), they are considerably less than the conditions normally used to simulate the effects of various alteration procedures in host rocks. The results obtained from the field and laboratory investigations were processed using Roclab code (Ver. 1.0, Rocscience) and rock mass parameters were determined (Table 2).

Numerical models

For estimation of load of pillars, the study of stress in pillars was carried out by applying the two dimensional finite difference codes. The use of two-dimensional model is suitable for the analysis of this problem because the exploited rooms are developed mainly in the longitudinal direction which makes it possible to disregard the three-dimensional effect due to the excavation face when the rooms have been excavated (Peila et al., 2008). The numerical models were developed as rooms excavated and the effect of sequence of room extraction was determined on load of pillar. The numerical model was evaluated under various horizontal-to-vertical stress ratios (K), ranging from 0.33 to 1.0. A comparison of the results of these sensitivity analyses with local observations and measurements, shows that K=0.5 produced the most closed results. It, therefore, was used for all the numerical models.

The results were obtained in terms of stress. Two points located at top and middle of pillars was considered and the vertical stress was recorded as ore extraction developed. Figures 7 to 10 present the results which obtained from the numerical models.

The achieved results show that the induced stress in pillars increased as rooms excavation completed. Also the plastic zone started to appear in model as the depth of mine increased. After extracting all rooms in models, it was observed that equal maximum vertical stress is

Table 1. Intact rock properties (Dehghan et al.2011)

Property	Orebody	Hanging wall	Foot wall
U.C.S. (MPa)	29	50	112
Young's Modulus (GPa)	15.9	16.2	32
Poisson's ratio	0.05	0.04	0.22
Cohesion (MPa)	4.2	4.8	6.4
Friction angle (deg)	53	55.4	55.3
Unit Weight (kN/m3)	38	27.1	27.1

Table 2. Rock mass properties from Roclab (Dehghan et al.2011)

Property	Orebody	host rocks
Modulus of deformation (GPa)	7.5	8
Poisson's ratio	0.25	0.22
Cohesion (MPa)	2.5	2.9
Friction angle (deg)	32	33

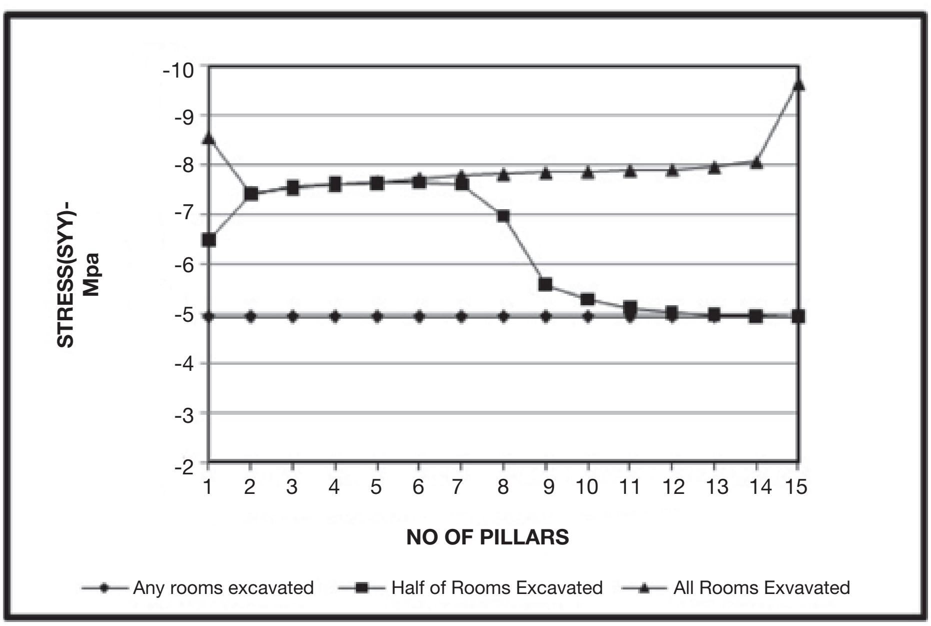

Figure 7. Effect of ore extraction sequences on stress distribution in phase 2 -Top of pillars (Dehghan et al. 2011)

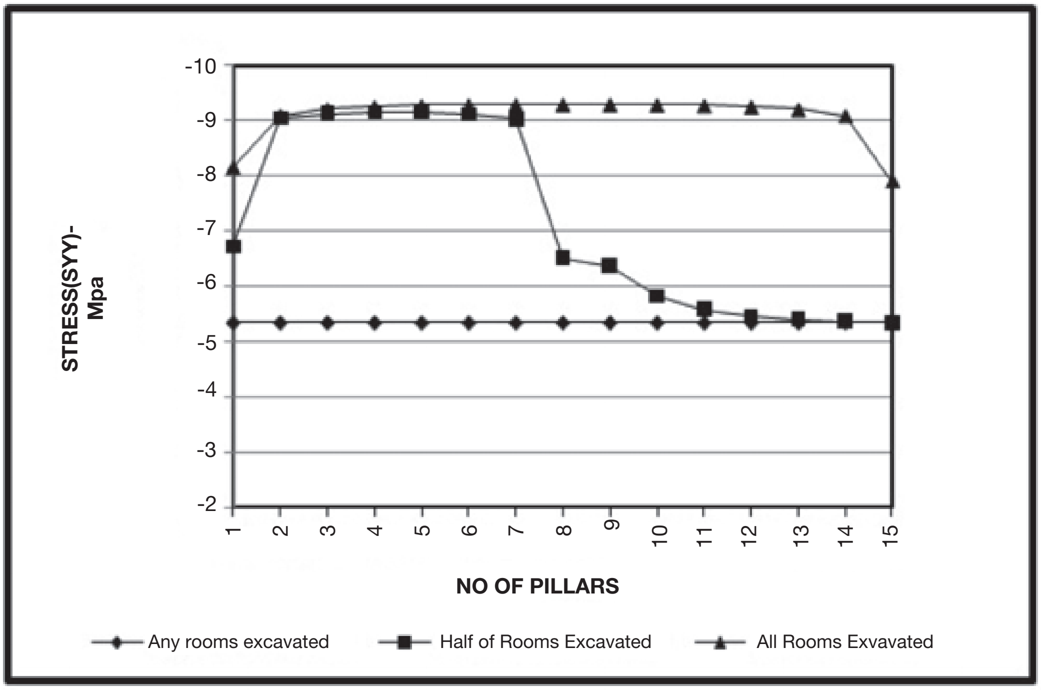

Figure 8. Effect of ore extraction sequences on stress distribution in phase 2 -Middle of pillars (Dehghan et al. 2011)

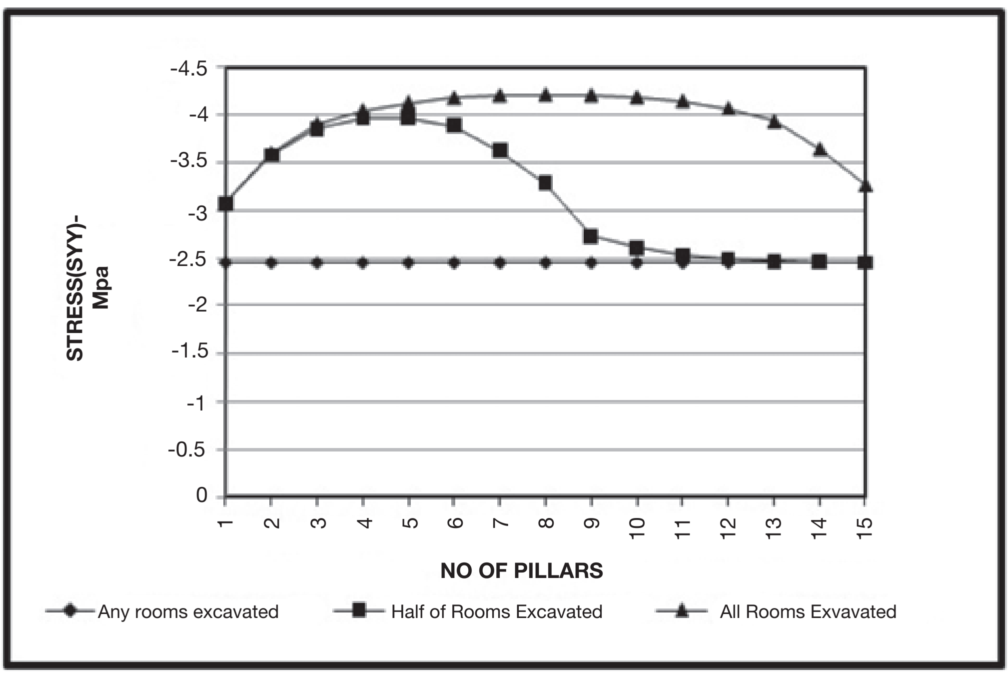

Figure 9. Effect of ore extraction sequences on stress distribution in phase 3-Top of pillars (Dehghan et al. 2011)

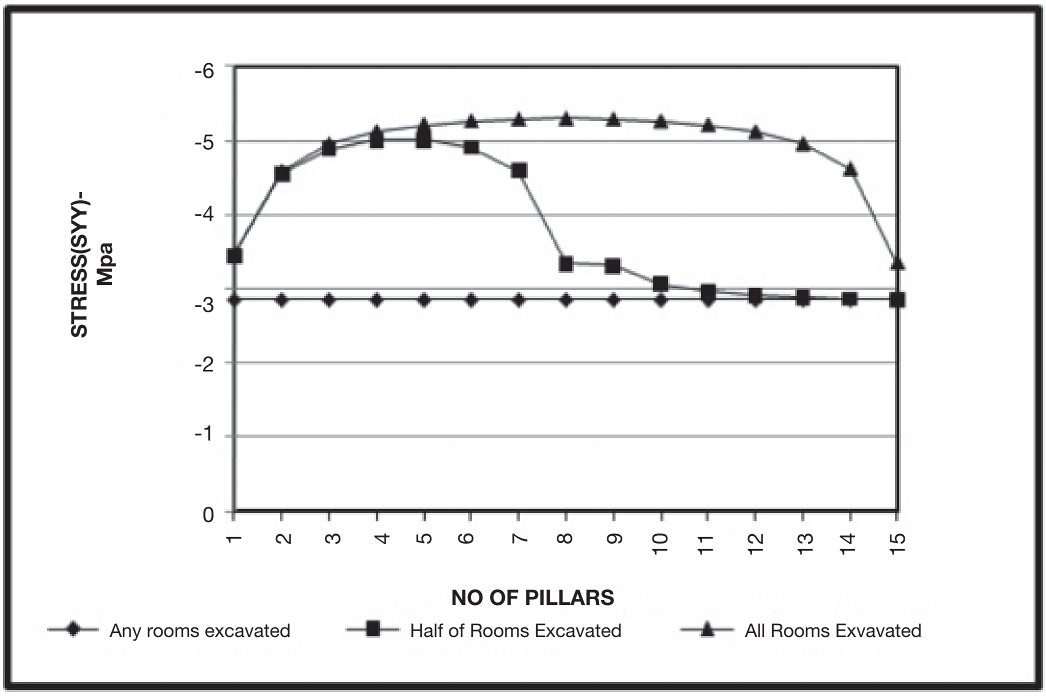

Figure 10. Effect of ore extraction sequences on stress distribution in phase 3-Middle of pillars (Dehghan et al. 2011)

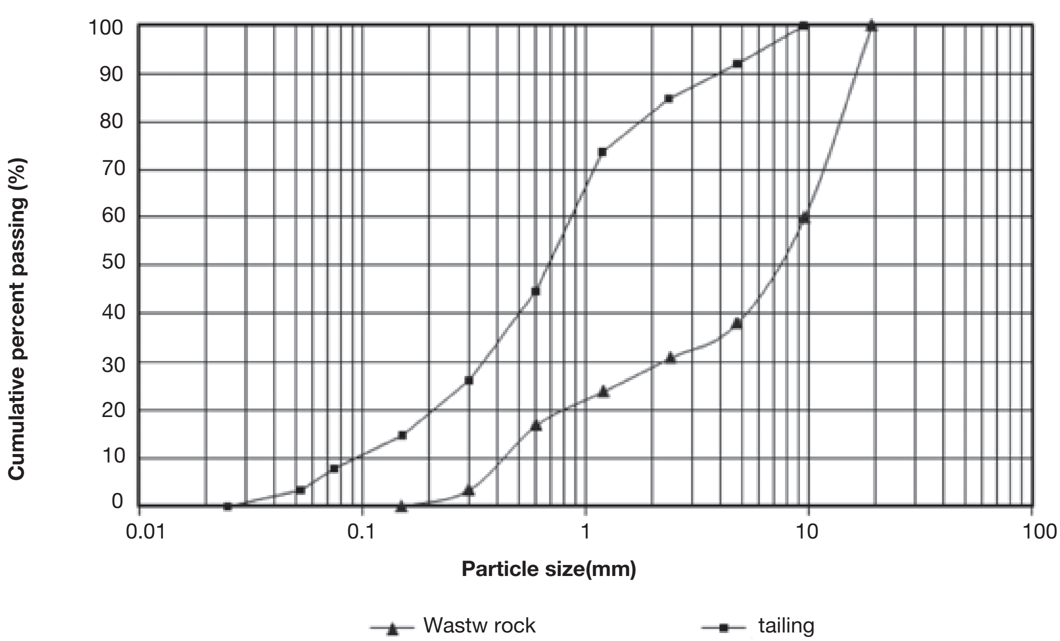

Figure 11. Grading curves for the backfill materials (Dehghan et al. 2011)

Table 3. Particle distribution parameters of the test materials (Dehghan et al.2011)

Element(Unit)	G_s(-)	D_{10}(mm)	D_{30}(mm)	D_{60}(mm)	C_u(-)	C_c(-)
Tailing	2.75	0.12	0.39	0.83	6.9	1.52
Waste rock	2.88	0.5	2.5	9	18	1.4

Table 4. Main chemical composition of tailing material (Dehghan et al.2011)

Element (%)										Sample No
C	P	S	MgO	CaO	Al_2O_3	SiO_2	Mn	Fe	Cr_2O_3	
0.79	0.0069	0.0409	36.11	1.53	0	25.77	0	5.53	7.42	Tailing
0.21	0.01	0.124	41.72	1.05	0	26.99	0	6.09	1.01	Waste rock

applied on all pillars due to the development of plastic zone to barrier pillars in phase2. However, the same was not observed in phase3 in which the maximum vertical stress applied on only middle pillars (pillar No 7,8 &9) as there was no plastic zone (Dehghan et al., 2011).

As shown in Figures 7 to 10, maximum stresses applied on pillars were seen 9.2 and 5.4 MPa for phases 2 & 3, respectively. By applying a safety factor of 2, the required uniaxial strength of backfill mixes has been determined in the range of 15-19 and 8.5-11 MPa for phases 2 & 3, correspondingly (Dehghan et al., 2011).

Laboratory tests

In comparison to other mines which used the stope and rip pillar with delayed backfill method and consideration of numerical modeling results, it was decided to make use of cemented backfill. To achieve this purpose, wide laboratory studies were done on all above mentioned waste material. As the nearest cement factory is located at 400 km of the mine, the transport cost of cement is high. To reduce operating cost of backfill, cement consumption and improvement of environmental conditions, investigations were done to replace cement by chromite slag. The effects of adding different percentage of chromite slag on cemented backfill properties such as UCS and young modulus were investigated further. As mentioned above, Iron, Zinc and Lead & Copper slags had previously tested in backfill mixes but chromite slag were used in this study for the first time.

Materials used

In the Faryab mine, there are three main sources of materials which can be used as base filling materials: surface mine waste rocks, washing plant tailings and alluvial sand. Because there is a large amount of surface mine waste rocks and washing plant tailings at the mine site, these material was considered in this study.

The particle size distributions of the test materials are presented in Figure 11. According to this Figure, the particle size distribution parameters such as Uniformity Coefficient (C_u) and Coefficient of Curvature (C_c) are determined. The results are illustrated in Table 3. Based on the C_u & C_c values, the materials can be classified into “well graded” materials (Hassani and Archibald, 1998; Das (1983)). Also, their main chemical elements were determined by chemical analysis which listed in Table 4.

In this study, the Portland cement type 2 and different combination of Portland cement with the chromite slag were considered as a binding agent. These types of binder were chosen to compare backfill mixes in term of gained strength. To compare the results, Portland cement was considered a base binding agent. It was used at 6% and 8% dry weight of the fill material. Also different blends of Portland cement and the chromite slag (PS) were used. For

Table 5. Main chemical composition of the chromite slag (Dehghan et al.2011)

Elements (%)													Sample No
Cao/Sio$_2$	L.O.I	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	
1.06	0.35	<0.1	1.57	13.61	32.85	0.58	0.07	34.99	0.27	12.05	0.34	3.19	S1
0.78	3.84	0.47	4.88	11.03	35.44	0.39	0.21	27.85	0.33	9.96	1.25	4.21	S2

Table 6. Mineralogical composition of the chromite slag (Dehghan et al.2011)

Crystalline mineral assemblage	Sample No
Olivine+ Spinel+ Quartz+ Chromite	S1
Olivine+ Calcite+ Quartz+ Hematite+ Spinel+ Chromite+ Serpantine	S2

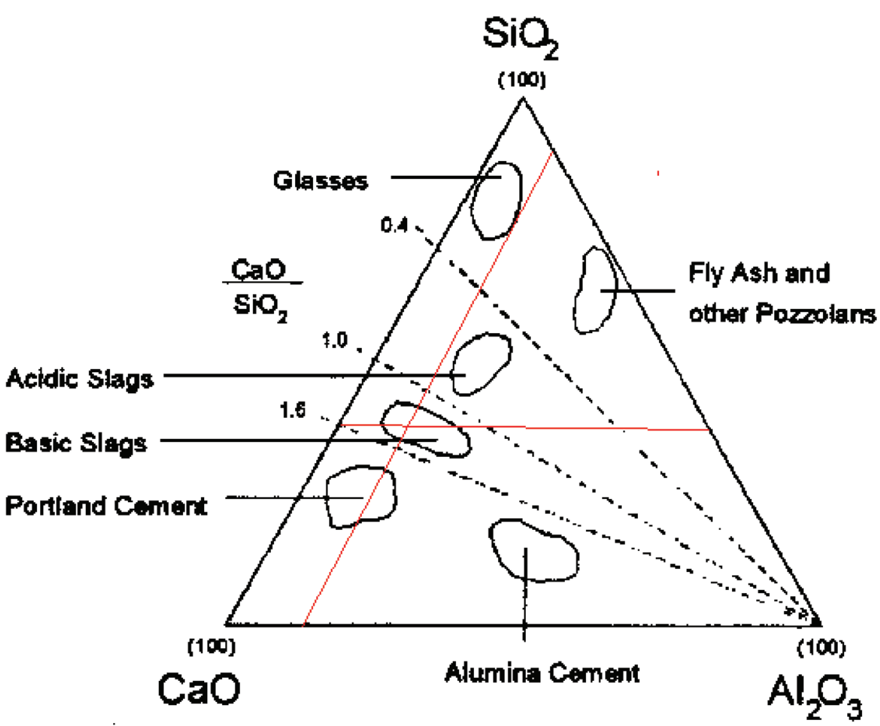

Figure 12. Classification of Chromite slag from Faryab mine by ternary diagram of binders(Hassani and Archibald, 1998).

example, the chromite slag /cement ratio was considered 2.5, 3, 4, 5 and 6 for cemented tailing backfills.

In Faryab mine, there are two types of chromite slag (S1&S2). The main chemical elements and the mineralogical composition of them were determined by atomic absorption spectrometry and X-ray diffraction analysis. The results are summarized in Tables 5 and 6. The regional observations show that there are considerable volumes of chromite slag type S1. So, it was chosen. According to ternary diagram of binders (Hassani and Archibald, 1998), S1 is classified as a basic slag (Figure 12).

Specimen preparation

By using above mentioned materials, two types of backfill mixes were prepared which named

Table 7. Effect of type of binder and binder content on mechanical behaviour of CTB (Dehghan et al.2011)

TYPE OF BINDER	E(kPa)		UCS(MPa)	
	7 day	28 day	7 day	28 day
%6 PC	181	207	1.32	1.67
%8 PC	273	320	2.16	2.2
%5 PC +15% Slag	202	222	1.4	1.7
%5 PC +25% Slag	250	271	1.6	1.9
%5 PC +30% Slag	270	300	1.85	2.25
%6 PC +15% Slag	335	400	2.2	2.5
%6 PC +25% Slag	316	513	2.5	2.72
%6 PC +30% Slag	397	572	3.2	4

Table 8. Effect of type of binder and binder content on mechanical behaviour of CRF (Dehghan et al.2011)

UCS(MPa)		E(kPa)		TYPE OF BINDER
28 days	7 days	28 days	7 days	
10.00	8.00	1405.00	715.00	6%PC
18.80	12.20	1725.00	978.00	8%PC
15.30	13.00	2025.00	1406.00	6%PC+25%Slag
21.00	16.86	2218.00	1638.00	8%PC+25%Slag

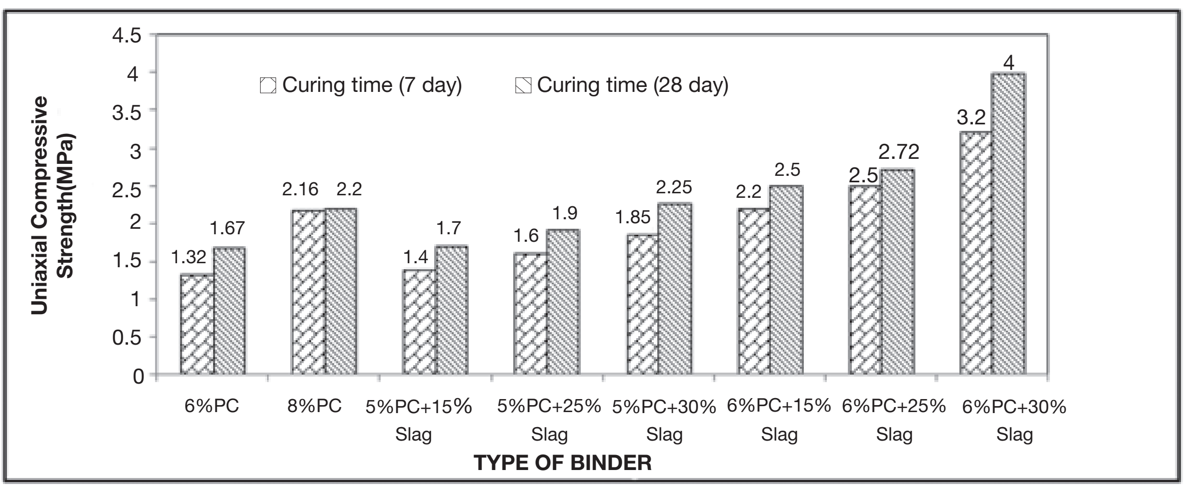

Figure 13. Effect of type of binder and binder content on uniaxial compressive strength of CTB (Dehghan et al. 2011)

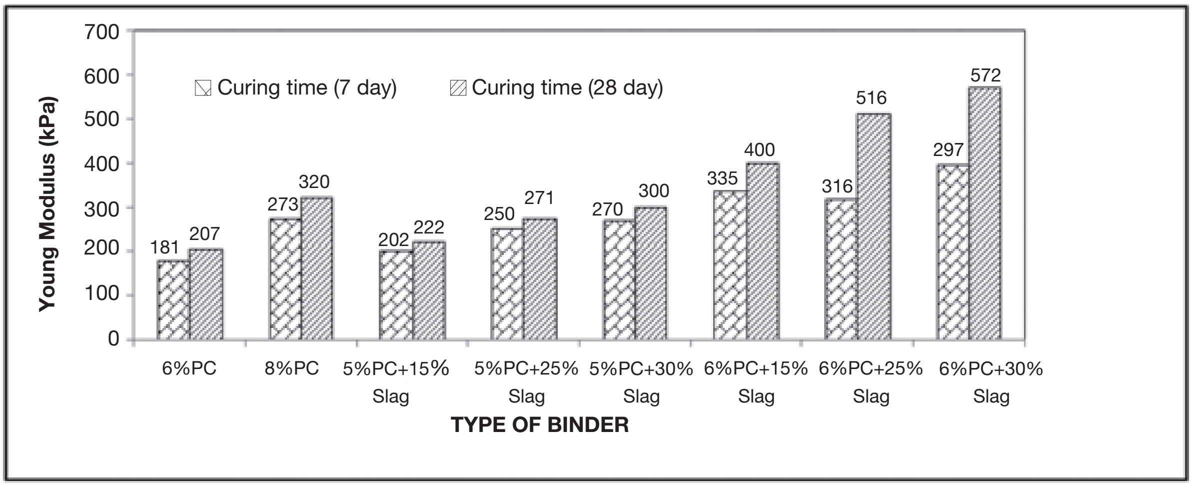

Figure 14. Effect of type of binder and binder content on Young modulus of CTB (Dehghan et al. 2011)

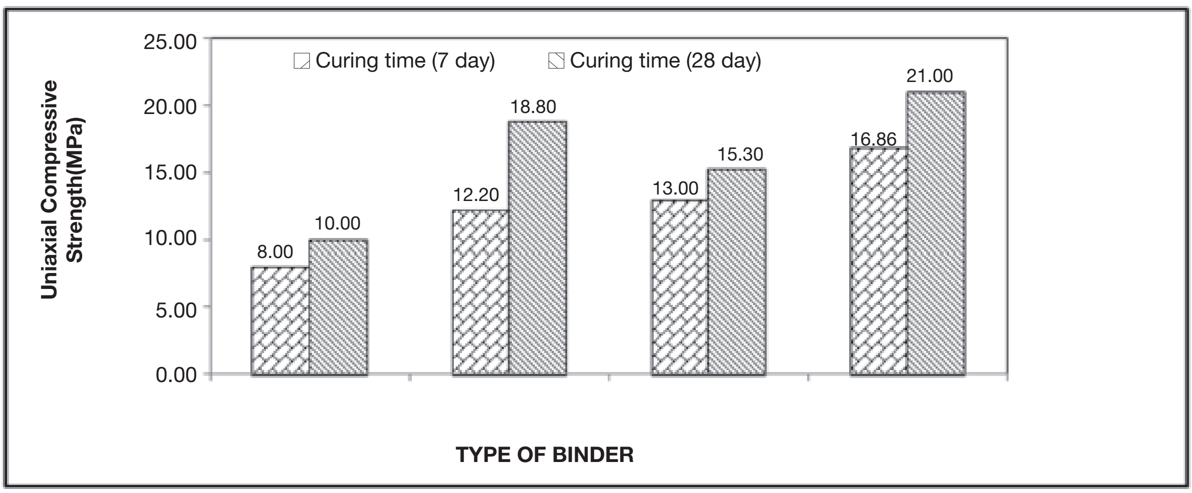

Figure 15. Effect of type of binder and binder content on uniaxial compressive strength of CRF (Dehghan et al. 2011)

in this study as Cemented Tailing Backfill (CTB) and Cemented Rockfill (CRF). Various batches of material were prepared in a rotary mixer to a uniform consistency. Then, the consistency of the CTB mixtures were measured by the slump test according to ASTM C 143(ASTM (2000a)). The test samples consisted of 100*100 mm and 150*150 mm cubic samples for CTB and CRF, respectively. The test samples were cured at ambient room temperature. The sample preparation and curing were in accordance with ASTM C192 and EN 12390 recommended procedures (ASTM, 2000b; BS, 2000a and 2000b).

Mechanical tests

Uniaxial compression tests according to EN were carried out to evaluate either the mechanical properties (UCS & E) or stress-strain

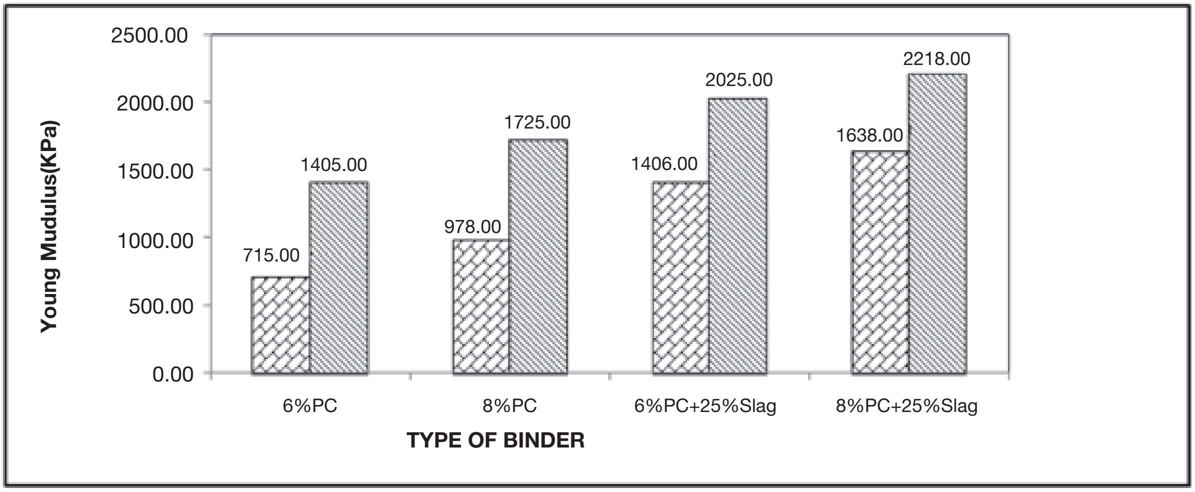

Figure 16. Effect of type of binder and binder content on Young modulus of CRF (Dehghan et al. 2011)

behavior of above mentioned samples (BS, (2000c)). To obtain these goals, the axial deformations were automatically recorded by a digital data logger system. The tests were carried out after 7 and 28 day-curing times. All of the experiments were carried out in triplicate and the mean values were presented in the results. The results of the UCS tests are summarized in Tables 7 and 8 and are presented in Figures 13 to 16. The results show that CRF, especially with chromite slag as a binding agent, can satisfy required strength which is estimated by numerical modeling while CTB can satisfy minimum required strength.

The results clearly show that the chromite slag improves the mechanical properties of all types of backfill mixes. It can reduce 2-3% cement consumption per 1 m^3 of backfill mixes. For first-level approximation this reduces 3,000,000$ of backfill operating cost in this mine.

CONCLUSION AND RECOMMENDATIONS

A literature review was conducted to provide background information for the use of refinery slag on backfill mixes. The review shows that iron slag has improved mechanical properties of cemented backfill materials but there isn't any background for using chromite slag in mines. In this study, a wide laboratory tests were conducted to determine the effects of chromite slag on mechanical properties of cemented backfill materials. For this purpose, chromite slag was blended with Portland cement in the range of 3-5 times of cement weight as a binding agent. The results showed that mechanical properties of backfill mixes have been improved.

On the other hand, accumulation of a large amount of different types of waste materials and ground subsidence due to caving of Fetr6 underground mine are the biggest environmental challenges of Faryab mines Co. To improve environmental conditions, the extraction method in Fetr6 underground mine changed into stope and rib pillars with delayed backfill. By consideration of ore body geometry in this mine, this method needs 700,000 m3 cemented backfill materials. It is clear that this volume of backfill materials and use of chromite slag as a binding agent would also benefit the mine environment by converting waste material into useful engineered product for ground support.

Additional works still remain to be carried out, however, in order to further characterize the properties of cemented backfill materials with chromite slag to permit their use in other mines. Future work should also focus on cost-effective methods for crushing and grinding of refinery chromite slag for using in backfill materials.

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