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THE EFFECT OF CHROMITE SLAG AS A BINDER AGENT ON STRESS-STRAIN BEHAVIOUR OF CEMENTED TAILING BACKFILL IN COMPRESSION, A CASE STUDY: FARYAB CHROMITE MINE

WPŁYW DODATKU ŻUŻLA ZAWIERAJĄCEGO SPOIWO W POSTACI CHROMITU NA WYTRZYMAŁOŚĆ NA ŚCISKANIE MATERIAŁU PODSADZKOWEGO ZAWIERAJĄCEGO ODPADY POGÓRNICZE Z DODATKIEM CEMENTU. STUDIUM PRZYPADKU: KOPALNIA CHROMITU (ŻELAZIAKA CHROMOWEGO) W FARYAB

Due to improving the environmental aspect and reduce the backfilling cost, the Faryab mine carry out researches into the replacement of cement by chromite slag. The test samples consisted of tailing from the washing plant of Faryab mine and different binders such as Portland cement, Pozzolanic cement and different combinations of Portland cement with chromite slag. The chromite slag produced by Ferrochromite refinery plant of this mine. The purpose of this paper is to analyze the findings from extensive laboratory test programs carried out to determine the effects of chromite slag on mechanical properties of cemented tailing backfills (CTB). The results show that chromite slag improves the mechanical properties of CTB samples. Also, the results indicate that chromite slag can be used as a replaceable material with cement and reduced 2-3% consumption of cement in 1 m^3 of backfill mixes. In addition, improving the environmental conditions can be achieved by reducing the cement content and moving tailing and chromite slag to underground stopes.

Keywords: Cemented Tailing Backfill, Chromite slag, binding agent, environmental effect

Z uwagi na wymogi ochrony środowiska oraz ze względu na konieczność obniżenia kosztów podsadzkowania, w kopalni Faryab prowadzone są badania nad możliwością zastąpienia cementu w materiale podsadzkowym żużlem chromitowym. Próbki do badań zawierały odpady z instalacji wzbogacania w kopalni Faryab oraz rozmaite spoiwa, takie jak cement portlandzki, cement pucolanowy oraz mieszanki cementu portlandzkiego z żużlem chromitowym. Żużel chromitowy pochodzi z instalacji wzbogacania

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w kopalni Faryab. Celem pracy jest analiza wyników szerokich testów laboratoryjnych przeprowadzonych dla określenia w jaki sposób obecność żużla chromitowego wpływa na właściwości wytrzymałościowe materiału podsadzkowego. Wyniki badań wskazują, że obecność żużla chromitowego poprawia właściwości wytrzymałościowe próbek. Ponadto, wyniki badań wskazują, że żużel chromitowy może zostać wykorzystany jako materiał zastępujący cement portlandzki w ilości 2-3% cementu na 1 m^3 mieszanki materiału podsadzkowego. Ponadto, działanie takie jest korzystne z punktu widzenia ochrony środowiska gdyż ogranicza się ilość cementu poprzez wprowadzenia dodatku chromitu do materiału wykorzystanego do podsadzania wyrobisk podziemnych.

Słowa kluczowe: materiał podsadzkowy zawierający odpady pogórnicze, żużel chromitowy, spoiwo, ochrona środowiska

1. Introduction

The Faryab mines are located 143 km northeast of the town of Bandar-e-Abbas, on the boundary between Kerman and Hormozgan provinces in Iran. The Faryab chromite deposit is the largest chromite deposit in Iran and one of the best-known chromite deposits in the world. This deposit includes six surface and three underground mines; however, operations in open pit mines ceased some time ago and all activities are now concentrated in underground mines. Of the various underground mines, Fetr-6 is the largest. Exploration has shown that the ore body of this mine is divided into three zones called Phases 1 to 3. The stope and pillar mining method was used as the main mining method for phase 1. In secondary mining stage of phase 1, the domino failure occurred which led to the destruction of 4000 m^2 of the mine area and mining operations consequently ceased for phase1. Studies show that W/H less than 1, an inadequate roof support system and the absence of a detailed program for recovery of pillars were the most important causes of the domino failure occurrence in this mine (Dehghan et al., 2011).

Following collapse occurrence in phase 1, the Faryab Co focused on ore extraction from phases 2 and 3. Since ore thickness in these phases is more than phase 1, it is necessary to consider a special layout of pillars to avoid collapse in them. The mining method planned for 100% extraction with complete pillar recovery (Faryab Co, 2008). This mining method includes rib pillar with delayed backfill. Figure 1 shows schematic view of this method. It was successfully used in Tara mine in Ireland, Cannon, Keretti and Carlin mines in the U.S (Brechtel et al., 1990).

In the mining industry, there are two basic types of backfilling strategies. The first, un-cemented backfilling does not make use of binding agents such as cement. The second, cemented

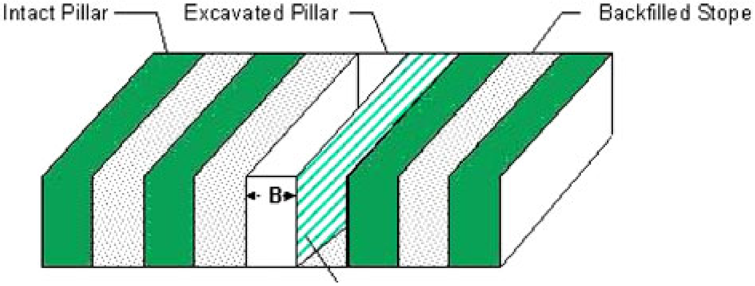


Fig. 1. Schematic view of strip pillar mining method in Fetr-6 underground

backfilling which makes use of a small percentage of binder such as Portland cement or a blend of Portland cement with gypsum, blast furnace slag or another pozzolan such as fly ash (Sivakugan et al., 2006). Investigations regarding the use of designed mining method for phase 2 of Fetr6 underground mine indicated that only the cemented backfill materials can be employed by this method. In this method, primary stopes will backfilled with cemented fill designed to carry the weight of the overburden. The primary backfilled stopes would later become backfill pillars, supporting the roof as the rock pillars mined. Uniaxial compressive strength of them is a critical factor for filling must remain stable.

Considering ore body geometry in this mine, this method needs at least 700,000 m^3 cemented backfill materials. Mine surveying in Canada shows that the cement content by weight ranged between 1 and 12% (average 6%), reflecting the standard use of low binder contents for bulk backfilling (De Souza et al., 2003). Thus, this company needs 110,000 tons cement for preparation of cemented backfill materials, approximately. As the nearest cement factory is located at 400 km of this mine, the transport cost of cement is high. In addition, there are different kinds of waste produced by different activities which majority of them is the Ferro-chromite refinery plant, in this mine. To reduce operating backfill costs, cement consumption and improve the environmental conditions, it is necessary to carry out investigations into the partial or total replacement of cement by the chromite slag. Thus, wide spread laboratory tests were done.

It is clear that this volume of backfill materials and moving the chromite slag and tailing to underground stopes, improve the environmental conditions and reduce the reclamation costs of this mine in future.

2. Literature survey

Cemented backfill operations have become expensive due to the increasing cost of production and transporting cement to mine sites. In addition, production and use of cement causes emission of greenhouse gases such as CO_2 (De Souza et al., 2003). These economic and environmental pressures have led mining companies to carry out researches into the replacement of cement by other materials. The investigations have shown that most important replaceable materials with cement are fly ash, slag, waste glass and gypsum (Petrolito et al., 2005). These materials are generally site specific, readily available and cost-effective relative to cement (Hassani et al., 1998).

Reviews have shown that using slag, especially iron and copper, have had a great effect on cemented backfill mixes properties especially their mechanical behaviors such as unconfined compressive strength and young modulus. The first tests with iron blast- furnace slag were done during the years of 1966-70 in Keretti mine. The tests were continued in the 70’s. The 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 (Niemeneh et al., 1983). Thomas and Cowling published the results of their investigations regarding the addition of furnace slag on the enhancing of backfill mixes strength at Mount Isa mine in 1978. According to their published results, strength of cemented backfill mixes would be developed if slag were added as a binder in the range of 4-5 times cement weight (Thomas et al., 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 saves over 25,000 tons 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 Portland cement. The curing time and hardening process were affected by zinc percentage in slag, consequently. So, he mentioned this is a restrictive element for the replacement of Portland cement by lead & zinc slag (Benkendorff, 2006).

The review shows that different kinds of slag especially iron slag enhanced mechanical properties of cemented backfill materials but no background was found for using the chromite slag in mines. As, the cemented tailing fills are one of the most widely used backfilling strategies in the world, extensive laboratory tests were done by the Faryab company to determine the effect of the chromite slag on unconfined compressive strength of them. The results of this study are presented in this paper. They can use in other mines especially underground chromite mines.

3. Experimental program

3.1. 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 washing plant tailings at the mine site, this material was considered and many attempts were carried out to obtain the mechanical behavior of cemented tailing backfill (CTB). The CTB samples typically consist of a mixture of cement, tailing and water.

– **Tailing materials**

The test materials for this study consisted of tailing from the washing plant of Faryab mine. In Figure 2, the particle size distribution of tailing materials is presented. 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 1.

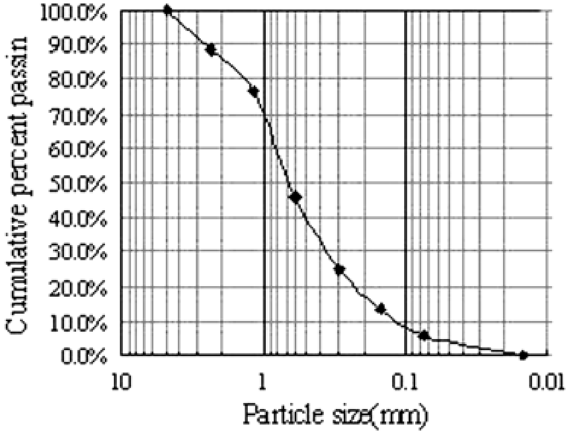


Fig. 2. Classification of the chromite slag from Faryab mine by ternary diagram of binders

TABLE 1

Particle distribution parameters of the test materials

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

Based on the C_u & C_c values, the tailings can be classified into "well graded" materials (Das, 1989). Also, their main chemical elements were determined by chemical analysis. The results are listed in Table 2.

TABLE 2

Main chemical composition of tailing material

Sample No	Element [%]									
	Cr_2O_3	Fe	Mn	SiO_2	Al_2O_3	CaO	MgO	S	P	C
T1	7.65	5.58	0	26.40	0	1.75	36.30	0.0397	0.0067	0.76
T2	6.68	5.44	0	25.44	0	1.40	35.67	0.0379	0.0071	0.8
T3	7.81	5.58	0	25.27	0	1.58	36.04	0.0389	0.0073	0.84
T4	7.55	5.51	0	25.96	0	1.4	36.42	0.0471	0.0067	0.76
Average	7.42	5.53	0	25.77	0	1.53	36.11	0.0409	0.0069	0.79

– Binders

In this study, the Portland cement type 2, Pozzolanic cement and different combinations of Portland cement with the chromite slag (PS) were considered as a binding agent. These types of binder were chosen to compare tailing mixes in term of gained strength. To compare the results, Pozzolanic and Portland cement were considered as a base binding agent. They were used at 6% and 8% dry weight of the fill material. Also different blends of Portland cement and the chromite slag were used. The chromite slag /cement ratio was considered 2.5, 3, 4, 5 and 6 for this study.

In this mine, there are two types of the chromite slag that their main chemical elements were determined by atomic absorption spectrometry. Also, the mineralogical composition of them is determined by X-ray diffraction analysis (XRD). The results are summarized in Tables 3 and 4.

TABLE 3

Main chemical composition of the chromite slag

Sample No		Elements [%]											
	Fe_2O_3	MnO	Cr_2O_3	TiO_2	CaO	K_2O	SO_3	SiO_2	Al_2O_3	MgO	Na_2O	L.O.I	Cao/Sio_2
S1	3.19	0.34	12.05	0.27	34.99	0.07	0.58	32.85	13.61	1.57	<0.1	0.35	1.06
S2	4.21	1.25	9.96	0.33	27.85	0.21	0.39	35.44	11.03	4.88	0.47	3.84	0.78

TABLE 4

Mineralogical composition of the chromite slag

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

The regional observations show that there are considerable values of the chromite slag type S1. So, it was chosen for the experiments. According to ternary diagram of binders (Hassani et al., 1998) this type of slag is classified as a basic slag (Fig. 3).

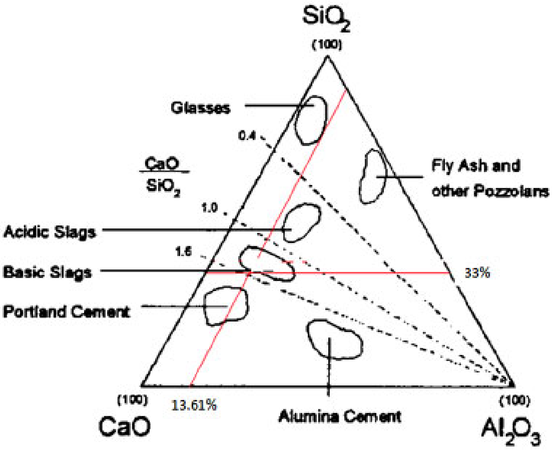


Fig. 3. Ternary diagram of binders (Hassani et al., 1998)

- **Additive**

To reduce the W/C ratio, RHEOBUILD 1100 was used as water reducing superplasticising admixture at the rate of 0.8-1.2 Litres per 100 kg of cement. The basic components of RHEOBUILD 1100 are synthetic polymers which allow mixing water to reduce considerably and strength to increase significantly, particularly at early ages. RHEOBUILD 1100 is a chloride-free product. It is compatible with all cements and admixtures meeting ASTM standards (BASF Co, 2008).

3.2. Specimen Preparation

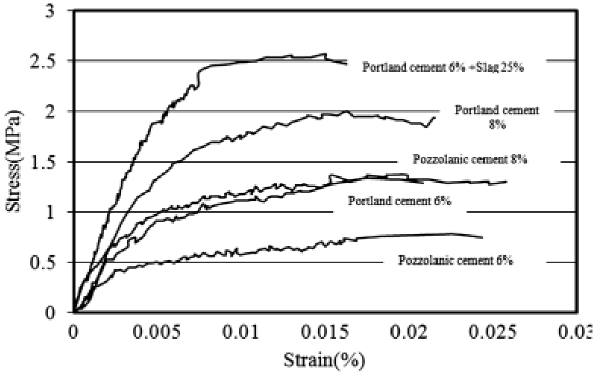
The preparation of CTB samples involves the blending of various fill materials. So, tailing materials, binder and water were mixed and homogenized to produce the desired CTB mixtures. Then, the consistency of the CTB mixtures were measured by the slump test according to ASTM C 143-90 (ASTM, 2000a). The test samples consisted of 100*100 mm cubic samples and were cured at ambient room temperature.

3.3. Mechanical tests

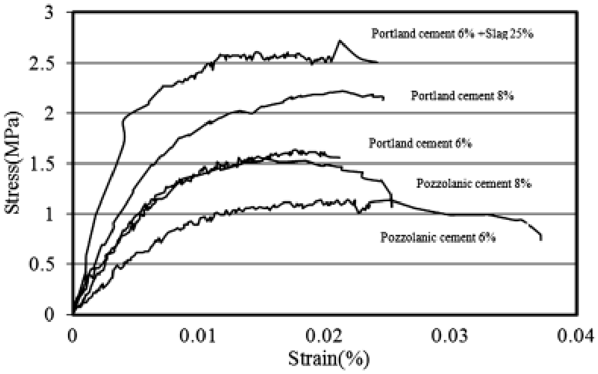
Unconfined compressive tests were carried out to evaluate the mechanical properties or stress-strain behavior of CTB samples. To obtain these objectives, the axial deformations were automatically recorded by a digital data logger system. All the experiments were carried out in triplicate and the mean values were presented in the results. To eliminate the effect of stress and strain rate on mechanical behavior of CTB samples (Jackson et al., 2008), these parameters were considered as constant in all the experiments. The tests were carried out after 7 and 28 day-curing times. The sample preparation, curing and testing were in accordance with EN 12390 recommended procedures (British Standards, 2000a, 2000b, 2000c).

4.

Figure 4 shows stress-strain behavior of CTB samples after mentioned curing time. The Figure both indicate the improvement of mechanical strength of CTB samples using chromite slag and the CTB samples using Pozzolanic cement had the least values compared with other types of binders. As it is clear from the Figure, the average 28-day UCSs values for the CTB samples with Pozzolanic cement (6%), Portland cement (6%) and PS, (6% (Portland cement) + 25% (chromite slag)) were 1.13,1.67 and 2.72 MPa, respectively. This means that using chromite slag led to 60% and 140% increment of strength in comparison with Portland and Pozzolanic cement respectively. Thus, different combinations of chromite slag with Portland cement were



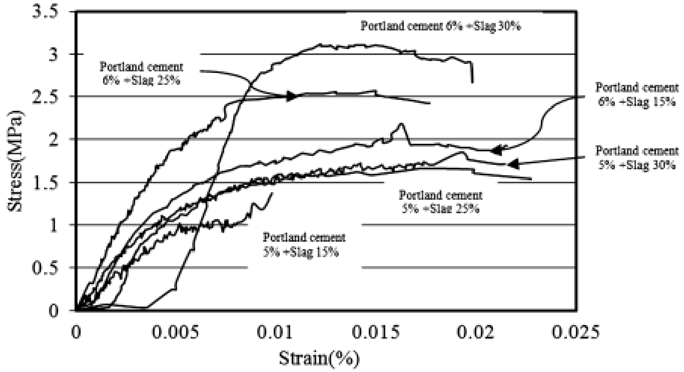
Curing period: 7 days



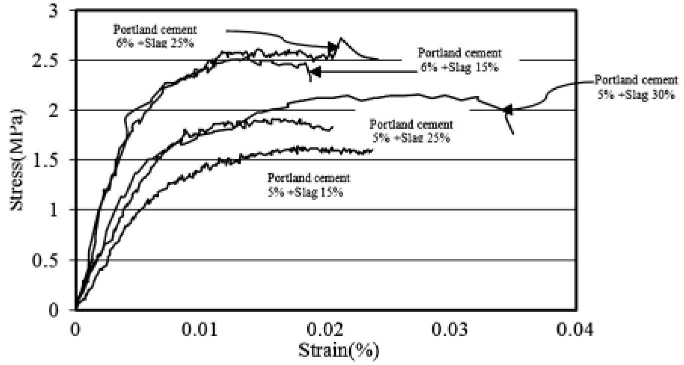
Curing period: 28 days

Fig. 4. Stress-strain curves for different types of binder

used for detailed investigation. These materials were blended together in the following proportions: P/S = 5/15%, 5/25%, 5/30%, 6/15%, 6/25% and 6/30%. The effects of chromite slag on the stress-strain curves of CTB samples are given in Figure 5. The total obtained results are summarized in Table 5 and shown graphically in Figure 6.



Curing period: 7 days



Curing period: 28 days

Fig. 5. Stress-strain curves for different combinations of chromite slag with Portland cement

The results show that the chromite slag has a considerable effect on mechanical properties of CTB samples. It increased the UCS and Young modulus of them. By increasing the slag content and curing period, these effects appear more clearly. For example, in a 7-day curing period, the UCSs of the CTB samples with 6% Portland cement and 15% chromite slag are equal to samples with 8% Portland cement. If the chromite slag is added to samples at rate of 4 and 6 times of cement weight, the strength of samples increased 15% and 48%, respectively. Whereas, in a 28-day curing period, using the chromite slag with the mentioned percentages led to the 13%, 23% and 81% increases of strength with respect of 8% Portland cement. The same results can be seen for Young modulus.

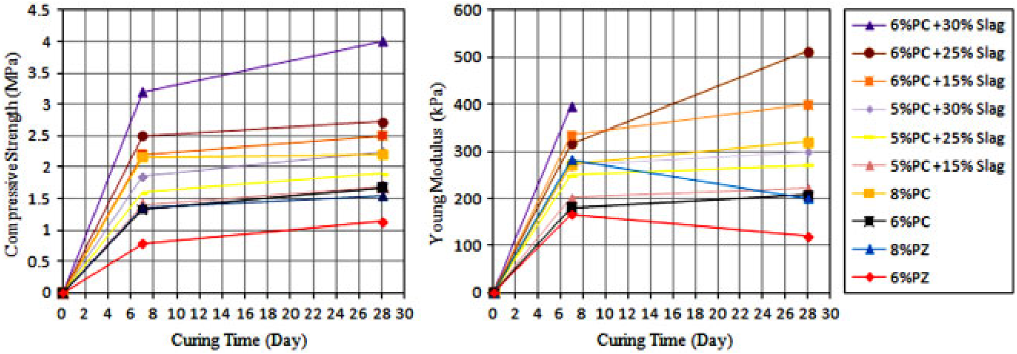


Fig. 6. Compressive strength and Young modulus of CTB as a function of curing period

TABLE 5

Effect of type of binder and binder content on mechanical parameters of CTB

Type of binder	**E [kPa]**		**UCS [MPa]**		**Type of binder**	**E [kPa]**		**UCS [MPa]**	
	7 day	**28 day**	**7 day**	**28 day**		**7 day**	**28 day**	**7 day**	**28 day**
%6 PZ	120	166	0.78	1.13	%5 PC +15% Slag	202	222	1.4	1.7
%8 PZ	200	283	1.36	1.55	%5 PC +25% Slag	250	271	1.6	1.9
%6 PC	181	207	1.32	1.67	%5 PC +30% Slag	270	300	1.85	2.25
%8 PC	273	320	2.16	2.2	%6 PC +15% Slag	335	400	2.2	2.5
%6 PC +30% Slag	397	N/A	3.2	4	%6 PC +25% Slag	316	513	2.5	2.72

Finally, the obtained results clearly show that the mechanical parameters of CTB samples created by PS were, in all cases, higher than that of the Portland or Pozzolanic cement.

5. Conclusions

In this study, the influence of different blends of Portland cement and the chromite slag as a binding agent on the mechanical parameters of cemented tailing backfill samples were compared with conventional binder such as Portland and Pozzolanic cement. For this purpose, the chromite slag was blended with Portland cement with the range of 2.5-6 times of cement weight.

The results show that mechanical properties of backfill mixes were improved by using chromite slag. For example, with comparing the results which illustrated in Table 5, it can be seen that the results of UCS tests of CTB samples containing 8% PC, as a binder, are approximately equal than combination of Portland cement and Chromite slag (PS) (6%PC + 15%Slag) or (5%PC + 30%Slag). Thus it can be concluded the chromite slag can reduce the consumption of cement by 2-3% per 1 m^3 of backfill mixes . For first-level approximation, this reduces 3,000,000$ of backfill operating cost in this mine. In addition, the use of tailing and the chromite slag can reduce the reclamation costs of this mine in future.

Further detailed studies are required to be carried out, however, in order to further characterize the properties of cemented backfill materials with the 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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