

Utilization of Bergama Gold Tailings as an Additive in the Mortar

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Abstract

Bergama is the first gold mine in the history of Turkish Republic and currently one of the operating gold mine in Turkey. About 3 tons of gold and equal amounts of silver are mined each year. The estimated ore reserves at the Bergama gold mine are 2.4 million tons with about 10 g Au per tonne of ore. About 277.882 tons of the tailings slurry of gold mine treatment is produced every year during the recovery of gold. Increasing amounts of tailings slurry cause a problem in large disposal areas. Therefore, the recycling of this kind of slurries into useful materials is quite important in terms of economic and environmental aspects.

The aim of this study was the investigation of utilization of the gold tailings as an additive material in Portland cement production. For this purpose, the effects of the gold tailings on the compressive strength properties of Portland cement were investigated. Cement mortars were prepared with Portland cement (CEM I 42,5 N) and dried gold tailings. Gold tailings with different ratios (5, 10, 15, 20, 25%) were added as cement additive in the mortar. The fresh properties of mortar such as consistency and setting time were investigated by using Flow table and Standard Vicat apparatus. The mortars were tested for compressive and flexural strength values after 3, 7 and 28 days. Mineralogical composition and microstructure of the 28-day mortars were determined by X-ray diffraction (XRD) and scanning electron microscope (SEM). According to results, it can be concluded that the tailings are eligible for mortar aggregate and the optimum ratio of gold tailings is 5%.

Keywords- gold tailings; setting time; compressive strength; XRD; SEM

1 Introduction

Mineral processing of hard rock metal ores (e.g. Au, Cu, Pb, Zn, U) and industrial mineral deposits (e.g. phosphate, bauxite) involves size reduction and separation of the individual minerals. The first stage of mineral processing is to crush and then grind and mill the ore. In the second stage of mineral processing, the ore minerals are separated from the gangue minerals (worthless materials). Consequently, the end products of ore or industrial mineral processing are residue wastes known as "tailings". Tailings typically are produced in the form of a particulate suspension, that is, fine-grained sediment water slurry [1].

Bergama gold mine, which is the first gold mine in Turkey, is located approximately 15 km west of Bergama town, about 100 km north of Izmir on the western coast

of Turkey and 15 km inland from the Aegean Sea. At the Bergama gold mine, gold is extracted from crushed ore using cyanide. In three years, the mine has produced approximately 10 ton of gold as well as 12 ton of silver [2, 3].

About 277.882 tonnes of the tailings slurry of Bergama gold mine treatment is produced every year during the recovery of gold. Most of the gold mine tailings are stockpile in the tailings dam. With the expansion and development of gold mining, the amount of tailings depositing increased year by year, which not only takes up a lot of land, causing environmental pollution around the reservoir area, but also requires a lot of money for the construction and maintenance of tailings management. Therefore, the comprehensive utilization of gold mine tailings has been important to resources utilization and environmental protection of the gold mine [4, 5].

The comprehensive utilization of gold mine tailings includes two aspects. First, recycling, the tailings are selected as a secondary resource to realize comprehensive recovery of useful minerals. Second tailings are to be used tailings directly as non-metallic mineral. Based on the actual situation, mine should choose one or a combination of both to achieve full use of the tailings resource [1].

Leea, Shang and Jeong [6] investigated Musselwhite gold mine tailings stabilized with fly ash for beneficial use as structural fill material. In this study, effect of adding fly ash to gold tailings (i.e., 0, 20, and 40% of the dry weight of tailings) was examined. Curing times are selected as 1, 3 and 5 days. According to the results, the compressive strength of the samples increases with the fly ash content. This is attributed to the denser packing as well as to the cementation generated by pozzolanic reaction.

Ramesh, Krishnaiah and Supriya [7] studied that the addition of various percentage of lime to the Red Earth treated with optimum percentage of mine tailings. Mine tailings was collected from an open dump from Kolar Gold Fields (KGF). After 30-day curing time, the strength increase was found to be maximum with 10% addition of mine tailings with curing, which was considered as optimum percentage. The increase in strength with the addition of 3% lime is treated as the optimum percentage. The use of lime by 3%, has the best result in compressive strength, both on the magnitude of increase in compressive strength, as well as from the value obtained compressive strength (840.4 kPa).

Vignesh, Reddy and Nachiar [8] reported that, in search of an alternative material for natural sand, Witwatersrand gold mine tailings are substituted partially for natural sand in the production of masonry mortars. In order to study the effect of replacing natural sand by gold mine tailings, natural sand was replaced with gold mine tailings at three percentages (10%, 20% and 30%). The mortar cubes were tested for compressive strength in a compression testing machine after 7, 28 and 56 days of curing. The compressive strength of cement mortar with gold mine tailings at 56 days was 3.73 MPa. The compressive strength of reconstituted river sand with 10%, 20% and 30% gold mine tailings at 28 days decreased by 31%, 35% and 57%, respectively.

Malatse and Ndlovu [9] used Witwatersrand gold mine tailings in making bricks. The results from XRD and XRF showed that the chemical composition of the Witwatersrand gold mine tailings is similar to that of the clay material used for commercial brickmaking. Different mixing ratios of gold tailings, cement and water were used. The bricks were tested for unconfined compressive strength. The results showed that the mixture with more cement than tailings had a compressive strength of approximately 530 kN/m².

In this study, utilization of the gold tailings as an additive material in Portland cement production has been studied. For this purpose, after characterization of tailings, the mechanical properties of samples, which consisted different amounts of tailings, were investigated for consistency, setting time, flexural strength and compressive strength.

2 Experimental

2.1 Raw Materials Preparation and Characterization

2.1.1 Gold tailings: The tailings slurry was provided from the Ovacik Gold Mine Treatment Plant, Turkey. The tailings slurry dried at 105°C for 2 hours. Dried tailings was ground with ceramic mortar and sieved to get a particle size below 75µm. The specific gravity of tailings was 2.60 g/cm³, which was determined with Le-Chatelier method. Blaine specific surface area of tailings was 2884.47 m²/kg. Dried tailings was subjected to X-ray diffraction (XRD) analysis, Philips PANalytical brand (Fig. 1) with Cu-Kα radiation source in the 2θ range from 7° to 90° at the parameters of 45kV and 40mA.



Figure 1. Philips PANalytical XRD



Figure 2. PANalytical MiniPal4 XRF

The chemical composition of the tailings was performed using PANalytical MiniPal4 X-ray fluorescence spectrometer (XRF) analysis (Fig. 2).

2.1.2. Cement: Ordinary Portland Cement (CEM I 42,5 N) was supplied from Akcansa Cement Industry and Trading Corporation. The specific gravity of cement was 3.12 g/cm³. Blaine specific surface area cement was 3666.26 m²/kg.

2.1.3. Aggregate: Standart sand was provided from Jeotest Ltd. Co according to Turkish Standart (TS EN-196-1) [10]. The specific gravity of sand was 3.24 g/m³.

2.2 Method

In this study, cement mortars were prepared with Portland cement and dried gold tailings. For this purpose, six cases were prepared for experiments, as listed in Table III. The amounts were chosen to determine the effects of gold tailings addition. These formulations were designated as BG00, BG05, BG10, BG15, BG20, BG25, respectively. As it can be seen from Table I, the BG00 formulation is used as reference.

To produce the mortar, dried gold tailings was added to cement in ratios of 0, 5, 10, 15, 20 and 25% (wt/wt). Cement, gold tailings, sand and deionized water were mixed with UTEST manual mortar mixer (Fig. 3) at room temperature.

In the experiments, a three cell mold with 4 x 4 x 16 cm inner dimensions was used to prepare the compressive and flexural strength samples. The mortar was put into the mold and the mold was vibrated by UTEST jolting table. The mold was put in the climate cabinet and left for 24 h for hydration under 20-25°C and 90% water-saturated air. After 24 h, the samples were left in water at 20°C for 3, 7 and 28 days. The procedure is shown in Fig. 4, schematically.

Table 1. Proportions of raw materials

Sample ID	Cement (g)	Tailings (g)	Sand (g)	Water/Binder
BG00	600	0	1800	0.50
BG05	570	30	1800	0.50
BG10	540	60	1800	0.50
BG15	510	90	1800	0.50
BG20	480	120	1800	0.50
BG25	450	150	1800	0.50



Figure 3. Cement mixer

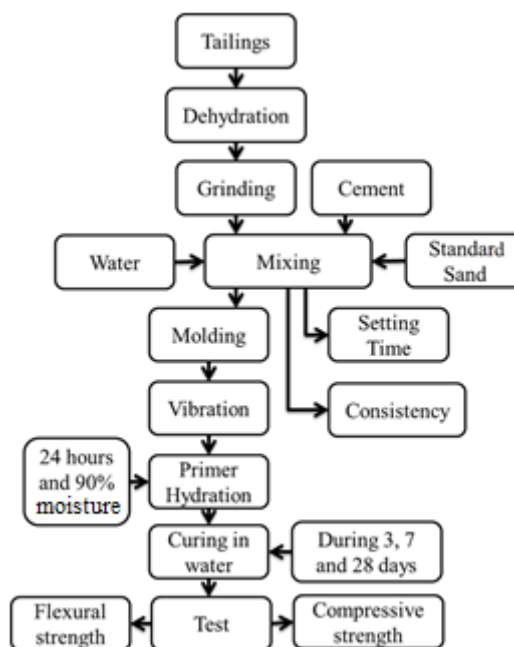


Figure 4. Flow diagram



Figure 5. Flow table

2.3 Test Details

The mechanical properties of mortar samples were tested for consistency, setting time, flexural strength and compressive strength.

Workability is the ease with which mortars can be spread to bed concrete bricks and building stones, and plaster or render concrete surfaces [11]. The consistency of fresh mortar was investigated by using UTEST Flow table (UTCM-0060/A Model) (Fig. 5) according to the Turkish Standard (TS EN 12350-5) [12].

Setting time of concrete is identified as the transition of fresh concrete from liquid phase to solid phase. It is important to identify this phase change to plan transporting and placing of concrete [13]. Turkish Standard (TS EN 480-2) [14] was used as a standard to evaluate the setting time with ATOM Standard Vicat apparatus (Fig. 6).

The compressive strength is the maximum stress that a material can handle without breaking. The flexural strength of mortar controls its ability to resist cracking [11]. After 3, 7 and 28 days of curing, according to Turkish Standards (TS EN 12390-3, TS EN 12390-5) [15, 16], the flexural and compressive strengths were measured in UTEST manual testing machine (Fig. 7).

Mineralogical composition of the 28-day mortars containing %5 tailings was determined with X-ray diffraction (XRD), Philips PANalytical brand with Cu-K α radiation source in the 2 θ range from 7° to 90° at the parameters of 45kV and 40mA (Fig. 1). Also, microstructure of the 28-day mortars containing %5 tailings was analyzed by Field-Emission scanning electron microscope (SEM), CamScan Apollo 300 brand

at 15 kV (Fig. 8). Magnification ratio was chosen as 5000x with Back Scattering Electron-BEI detector.



Figure 6. Standard Vicat apparatus



Figure 7. Manual testing machine

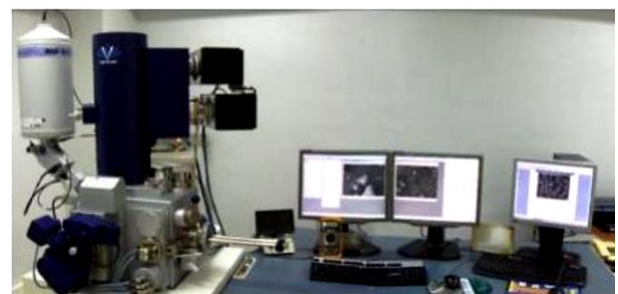


Figure 8. Field-Emission scanning electron microscope

2.4 Result of Gold Tailings Characterization

3 Results and Discussion

3.1 Result of Gold Tailings Characterization

According to Figure 9 and Table II, it can be seen that "01-089-1961" pdf numbered "quartz" SiO₂ is the major phase in gold waste.

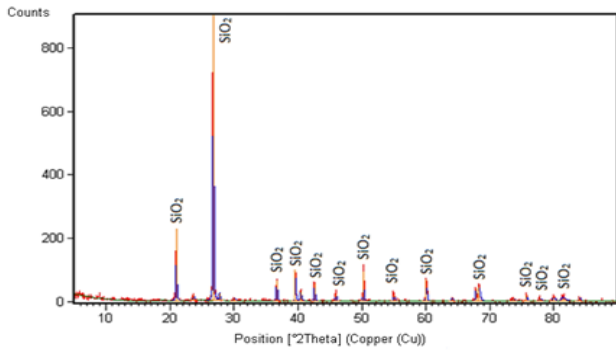


Figure 9. XRD pattern of Bergama gold mine waste

Table 2. XRD results of tailings

Raw Material	Reference Code	Mineral Name	Mineral Formula	Score
Bergama Gold Mine Waste	01-089-1961	Quartz	SiO ₂	93

Table 3. Chemical composition of the tailings according to XRF analysis

Compound	Content (wt%)
SiO ₂	92.9
K ₂ O	2.9
CaO	0.63
TiO ₂	0.13
MnO	0.063
Fe ₂ O ₃	3.14
CuO	0.065
BaO	0.2
PbO	0.055

Chemical composition has an important influence both on the potential application of tailings. The composition of the tailings was shown in Table II. As listed in Table III, tailings is comprised of SiO₂, Fe₂O₃, K₂O, CaO, BaO, TiO₂, CuO, MnO and PbO.

3.1 The mechanical properties of mortar samples

The influence of tailings on setting time is shown in Fig. 10.

According to Fig. 10, it can be seen that initial time started to decrease when gold tailings content was increased 5 to 25% in cement. The initial time has maximum value (229 min) when tailings ratio was 5%, but final time had maximum value (362 min) when ratio was 10%.

Table VI shows flow values of samples. According to the results, the amount of tailings added increased the consistency.

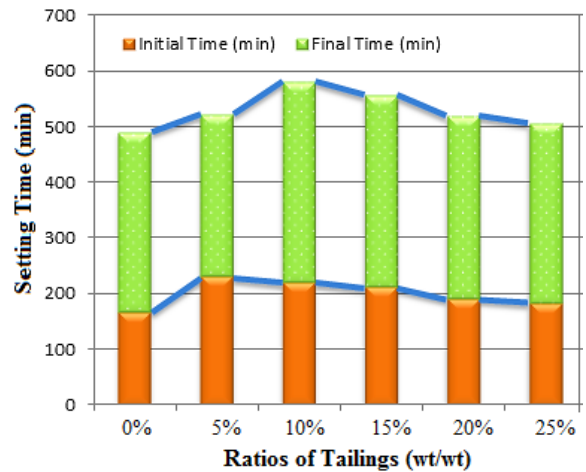


Figure 10. Effect of gold tailings content on the setting time

Table 4. Flow values of mortars

Sample ID	Slump (cm)
BG00	13.5
BG05	12.95
BG10	13.12
BG15	13.63
BG20	13.95
BG25	14.35

The compressive and flexural strengths of mortar samples produced by adding different amounts of gold tailings were determined and the results are presented in Table V and VI.

As can be seen from Table V and VI, the optimum gold tailings content, which gives the maximum compressive and flexural strength at the age of 28 days, is 5 wt% of

gold tailings. The 3-day compressive strength of the mortar produced using gold tailings (10%) was 34.14 MPa, compared to 34.09 MPa for the Portland cement. The 28-day compressive and flexural strength decreased by 35.52% and 17.91%, respectively, when the gold tailings content was increased from 0 to 25%.

Table 5. Effect of gold tailings content on the compressive strength

Sample ID	Tailings Content (wt%)	3 Days (MPa)	7 Days (MPa)	28 Days (MPa)
BG00	0	34.09	42.5	54.67
BG05	5	34.01	42.37	51.79
BG10	10	34.14	42.06	51.19
BG15	15	29.07	36.05	45.84
BG20	20	24.09	30.82	39.71
BG25	25	22.94	20.82	35.25

Table 6. Effect of gold tailings content on the flexural strength

Sample ID	Tailings Content (wt%)	3 Days (MPa)	7 Days (MPa)	28 Days (MPa)
BG00	0	5.52	6.00	7.98
BG05	5	5.38	5.99	7.58
BG10	10	5.81	5.97	7.49
BG15	15	4.79	5.48	6.83
BG20	20	4.02	4.96	6.93
BG25	25	3.74	4.82	6.55

3.3 Mineralogical composition and microstructure of mortar samples

According to result of strengths, optimum ratio of gold tailings is 5%. XRD results of mortar samples containing %5 tailings are given in Fig. 1 and Table VII.

According to Fig. 9, XRD pattern of gold tailings exhibits presence of silica and gismondine. It can be seen that from Table VII, scores of "00-033-1161" pdf numbered "silica" SiO₂ and "00-020-0452" pdf numbered gismondine are 73 and 28, respectively.

Microstructure of mortar samples containing %5 tailings is shown in Fig. 10. From SEM result, heterogeneous structure can be seen.

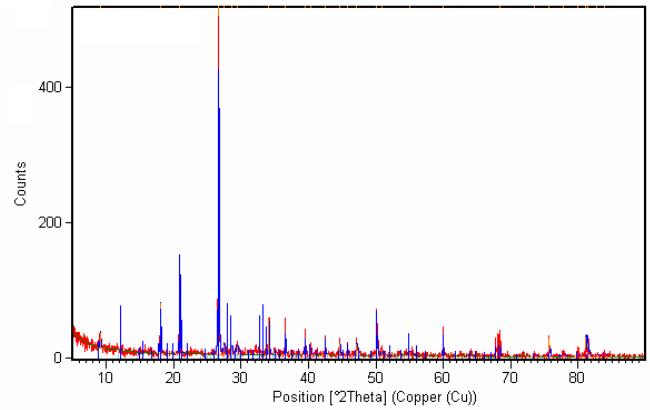


Figure 9. XRD pattern of mortar containing 5% tailings

Table 7. XRD results of mortar containing 5% tailings

Reference Code	Mineral Name	Mineral Formula	Score
00-033-1161	Silica	SiO ₂	73
00-020-0452	Gismondine	CaAl ₂ SiO ₈ (H ₂ O)	28

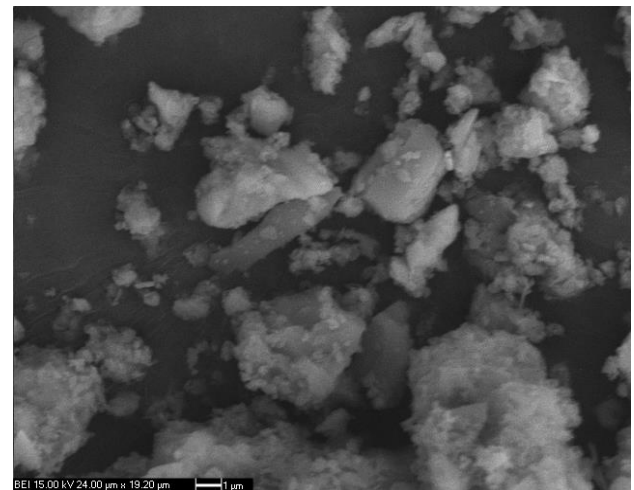


Figure 10. SEM image of mortar containing 5% tailings

4 Conclusion

In this study, gold tailings as an additive in the mortar was investigated. Characterization of gold tailings showed that major content of tailings is SiO₂. Utilization of gold waste in different industrial application ensures environmental sustainability and economic benefits

because of its SiO₂ content. For this purpose, mortar mixtures were prepared with different ratios of gold tailings. After production of mortar, the mechanical properties, mineralogical composition and microstructure of the samples from these mortar samples were determined. It was observed that an increase in the amounts of tailings in cement from 5 to 25% caused a decrease in the compressive strength of the mortars. As a result, it is suggested that gold tailings can be used as cement additives up to 5% maximum, giving the 28-Day compressive strength for the mortar of 51.79 MPa.

In future studies, chemical additives can be used in the production of mortar containing gold tailings. In this way, the 28-day compressive strength of the mortars could reach up higher than previous results.

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