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Full Length Article

Mill tailings based composites as paste backfill in mines of U-bearing dolomitic limestone ore

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This paper elaborates on the development of paste backfill using mill tailings generated during the processing of a uranium ore deposit hosted in dolomitic limestone. The tailings have been characterized in terms of the physical, chemical and mineralogical properties. Time-dependent rheological behaviors and geotechnical properties of cemented paste backfill (CPB) are also determined. The studies show that the mill tailing has the potential to form paste and the CPB has adequate strength to provide support to mine pillars, roofs, and walls.

1. Introduction

Each year, a huge amount of mill tailings with different compositions is produced from processing plants throughout the world (Yilmaz et al., 2012). The surface disposal of the mine wastes is a serious problem due to its environmental impacts, occupation of large surface-footprint, and excessive water inventory. For this, new technologies such as paste backfill in underground mines have emerged as alternative methods to surface disposal, facilitating the mining industry to reutilize such environmentally hazardous materials as support system and thereby minimizing or sometime eradicating harmful effects (Yilmaz et al., 2015a; Deng et al., 2017). Paste backfill improves ground support for mine structures with high recovery of ore bodies and at the same time, eliminates mine dewatering, reduces storage requirements for surface tailings and rehabilitation costs, thereby reduces the affiliated environmental risks (Brackebusch, 1995; Sheshpari, 2015; Jiang and Fall, 2017). Paste backfill is generally considered to be a high-density non-segregating mixture that contains 70–85% solids and at least 15% particles finer than 20 μm to prevent settlement when transported through a pipeline for disposal (Klein and Simon, 2006). The design requirements for the structural integrity of paste backfill are governed by physical, chemical and mineralogical properties of paste backfill ingredients (Benzaazoua et al., 1999; Fall and Nasir, 2010). Benzaazoua et al. (2002) emphasized the strong dependency of geomechanical strength gain of paste backfill on the characteristics of three basic constituents, namely tailings, binder, and mixing-water. Yin et al. (2012) and Yılmaz and Ercikdi (2016) observed that increases in solid concentration and binder content can improve the mechanical properties of paste backfills but decrease the rheology thereof. Furthermore, Mohamed et al. (2002) evidenced that incorporation of additives (lime, fly ash and aluminum) in sulphide-rich tailings based paste backfill improved the mechanical strength and consistency, and reduced saturated hydraulic conductivity. In order to assess the suitability of granular mill tailings as paste backfill, its properties and behaviors are required to be determined independently (Yilmaz et al., 2011a). Studies are required for optimizing the behavior of cemented paste backfill (CPB) for ground support, environmental issues and cost aspects.

This study on mill tailings of a uranium ore deposit ascertains its suitability as paste backfill mainly for two reasons: (i) paucity of land for disposal and water for hydraulic filling, and (ii) ore extraction from hanging wall lode of ore body may not be possible without proper paste backfilling. The paper attempts to understand

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the rheological, geomechanical strength, and deformation behaviors of CPB composed of mill tailings of carbonate-rich uranium waste such that the surface foot print of the mill solid rejects is minimized in addition to providing sufficient support to side walls, roofs and pillars for mining additional ore. However, since CPB's material properties are known to be time-dependent due to the progressive cement hydration reaction (Lu et al., 2017), the paper provides results of the above studies and establishes unique relationship between the hydration process and rheological and strength properties of CPB. The paste backfill technology is in nascent stage in India and the study reported here is the first attempt to characterize the carbonate-rich uranium processing waste as paste backfill material. It assumes further significance as the investigations provide pointers to handle huge volumes of mine rejects in countries where habitation is close to ore bodies. Apart from summarizing the various test procedures, the paper provides significant data related to the physical, chemical, rheological, and geotechnical behaviors of CPB for carbonate-rich mill tailings and will be helpful for future research findings.

2. Materials and methods

Physical, chemical, mineralogical, morphological, rheological, and geotechnical properties of paste backfill and its ingredients are studied on the tailings (leach residue) obtained during hydrometallurgical processing of a dolomitic limestone bearing uranium ore as per ASTM (American Society for Testing and Materials) and IS (Indian standard) methods. Similar methodologies for characterizing paste backfill and its constituents have been reported by several researchers (Yilmaz et al., 2007, 2011a,b, 2014a,b, 2015a,b; Ghirian and Fall, 2013, 2014). It may be noted that the CPB's parameters, i.e. water content w, solid concentration C_w, binder content B_w and superplasticizer dosage SP which are used in subsequent sections of this paper, are calculated as follows (Koupouli et al., 2016):

$$w = \frac{1 - C_w}{C_w} = \frac{M_{\text{water}}}{M_{\text{dry-solid}}} \tag{1}$$

$$C_w = \frac{M_{\text{dry-solid}}}{M_{\text{dry-solid}} + M_{\text{water}}} \tag{2}$$

$$B_w = \frac{M_{\text{dry-binder}}}{M_{\text{dry-tailings}}} \tag{3}$$

$$SP = \frac{M_{\text{SP}}}{M_{\text{dry-binder}}} \tag{4}$$

where M_{water} is the mass of water, $M_{\text{dry-binder}}$ is the mass of dry binder, $M_{\text{dry-solid}}$ is the mass of dry tailings and dry binder, and M_{SP} is the mass of superplasticizer.

2.1. Tailings, binder and superplasticizer

The tailing samples under investigation have been collected from a dolomitic limestone bearing uranium ore processing mill located in south India (Gupta and Sarangi, 2011). The samples are preserved in sealed plastic containers to prevent pore water loss and occurrence of oxidation prior to their subsequent usage in laboratory experiments. Before experiments, the tailing samples are homogenized by thoroughly mixing and sub-samples are prepared by coning and quartering. The other CPB ingredients used in this study are municipal tap water as mixing water, ordinary Portland cement (OPC) of 43 grade (IS: 8112, 2013) as binder, and polycarboxylate (PC) based superplasticizer (IS: 9103, 1999) as high-range water reducer admixture.

2.2. Physical characterization tests

The study encompasses laboratory experiments, mainly specific surface area, particle size distribution, specific gravity, saturated hydraulic conductivity (saturated permeability) and Proctor compaction test. Specific surface area is evaluated as per (ASTM D6556-16, 2016) by measuring nitrogen (N_2) multi-point adsorption isotherms using Automated Gas Sorption Analyzer (Autosorb-1, Quantachrome Instruments) based on the BET (Brunauer, Emmett, and Teller) method. The particle size analysis is conducted using a Malvern particle size analyzer (Mastersizer 2000 E Ver. 5.20, UK). The specific gravity of tailings is determined according to IS: 2720-Part 3 (1980) standard. Saturated hydraulic conductivity of tailings is determined as per ASTM D5856-15 (2015). To evaluate the optimum moisture content (OMC) and the maximum dry density (MDD), the Proctor compaction tests are performed as per ASTM D698-12e2 (2012).

2.3. Chemical characterization tests

The chemical composition of the tailing samples is determined by wet chemical analysis and X-ray fluorescence (XRF) spectrometer (Axios, PANalytical). In addition to this, energy-dispersive X-ray spectroscopy (EDX) coupled to scanning electron microscopy (SEM) is also used for the similar purpose. ZEISS EVO 60 (Carl ZEISS SMT, Germany) SEM is used to characterize the microstructure and texture of the tailing sample. Secondary electron (SE) imaging mode is used for creating images. EDS detector (INCAPentaFET-x3, Oxford Instrument, UK) probe coupled to the SEM is used to aid the qualitative and quantitative elemental composition partial analysis of the tailings.

2.4. Mineralogical and morphological characterization tests

Due to the highly variable nature of the local geology in the mine site, it is important to assess the mineralogical properties of tailings. Mineralogy of tailings significantly influences the rate of strength gain and final strength of backfill (Potvin et al., 2005). In this study, X-ray diffraction (XRD) spectrometer (PW: 3040/60 X'pert PRO, PANalytical, Netherlands) is used to determine the mineralogical composition of the tailings. In addition, ZEISS MERLIN field emission SEM (FE-SEM) has been used for studying morphology of developed paste backfill.

2.5. Determination of pH value of tailings and leachate of CPB

The pH value is measured as per IS: 2720-Part 26 (1987) by a Benchtop meter (Thermo Scientific Orion VERSA STAR) coupled with pH electrode (Orion, 8172BNWP, ROSS sure-flow).

2.6. Rheological characterization tests

Rheology tests on the slurry are necessary for evaluation of the colloidal characteristics and pipeline transport potential of uncemented/cemented paste backfill. These tests are conducted for (i) estimation of slump height using slump cone tests, and (ii) determination of yield stress using rheometer.

2.6.1. Slump

The slump height determination allows characterizing the material's consistency in terms of transportability/pumpability. Slump

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