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Variability in rheology of cemented paste backfill with hydration age, binder and superplasticizer dosages

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ABSTRACT

The use of (CPB) material to ameliorate geotechnical stability of underground mine is in nascent stage in India. Rheological properties of CPB change with travelling time as it is transported to underground mine stope through pipeline reticulation. In this paper, rheological properties of CPB based on mill tailings of a carbonate rich mineral processing waste are evaluated for different dosages of polycarboxylate (PC) based (SP). Each CPB sample having 78 wt% solids is mixed separately with 4%, 6% or 8% of binder dosages (ratio of the weight of dry binder to the weight of dry tailings) and, 0%, 0.5%, or 1.0% of SP dosages as weight of dry binder. The paper presents a methodology for determining yield stress, plastic viscosity and thixotropic behaviour of CPB mixture as a function of hydration age, binder and SP dosages. Results from the experimental campaigns indicate that SP content has significant influence on rheological behaviour of CPB and can be suitably exploited to enhance the flow characteristics of the carbonate rich process tailings. The study also develops multivariate linear regression models of yield stress, plastic viscosity and thixotropy of CPB depending on the hydration age, binder and SP dosages.

1. Introduction

Extraction of valuable minerals from low grade ores results in the generation of huge quantity of mill tailings [1]. On the other side, underground mining leaves voids in the form of stopes which may create serious instability of underground structures. Cemented paste backfilling of tailings in underground stopes is an environmentally friendly technology which reduces surface footprint of tailings dams as well as enhances the stability of underground structures. CPB material is often considered to be a high density non-segregating mixture which contains 70–85 wt% solids with about 15 wt% particles less than 20 μm. Such granulometry prevents settlement with negligible bleeding of water when transported through a pipeline for disposal [2]. Hydraulic binders like cement in the dosage of 1–7 wt% by dry mass of tailings are integral part of any CPB material which gradually augments additional cohesive and mechanical strength during its curing [3]. Increasing the solid content rather than the binder quantity is a more economic way to get higher strength of CPB mixtures, since binders account for 75 to 80% of the total backfilling operation cost. Typically, fresh CPB is delivered from surface CPB plant to underground stopes by gravity and/or pumped through pipeline reticulation system. However, during transportation, CPB having high solid concentration with minimal water to cement ratio (w/c) may cause significant friction losses and clogging of the pipeline due to change in its rheological behaviour as a function of hydration age. The change in rheological properties of CPB during transportation of CPB though pipeline is caused since the moisture content reduces due to continuous hydration reaction of cement within CPB matrix, and hence interparticle bonds gradually become stronger. In order to alleviate such constraints, superplasticizer (SP) also known as high-range water reducer (HRWR) admixture in specific dosages is added to optimize the solid content in CPB for desired transportability/pumpability. Ercikdi et al. found that, after incorporating SP in the CPB, the moisture content reduced by about 6.6% for a given slump and CPB material additionally offered better resistance against internal sulphate attack compared to a control CPB material without superplasticizer [4]. Thus, pipeline transportation of fresh CPB is one of the critical stages in CPB design and hence, the rheology of the CPB must be understood in order to optimize its flow characteristics to render efficient pumping with minimal friction losses. Yield

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stress, plastic viscosity and slump are the key rheological parameters for evaluation of the transportability of CPB material for pipeline reticulation system design [5,6]. Yield stress indicates the interparticle attractive forces and is the critical shear stress which causes irreversible plastic deformation to start the flow of a concentrated fluid in the pipeline. Yield stress must be in optimum range which enables laminar CPB transport in pipeline (velocity range 0.1 m/s to 1.0 m/s) without settlement of the solids. Plastic viscosity represents the frictional resistance between two layers of concentrated fluid in flow regime. Slump parameter also characterizes the consistency of CPB material in terms of transportability/pumpability. CPB material having solid content ranging from 70 to 85% are generally optimized to obtain a target slump in the range of 15.20–25.40 cm to provide improved rheological characteristics and to facilitate efficient transport [7,8]. However, Sivakugan et al. claimed that slump value of CPB may range from 23.5 to 27.5 cm for different mine sites for efficient pipeline transport [9]. It is well known that rheology of CPB is affected by many factors e.g. solid concentration, cement type and its dosage, chemical additive and its dosage, particle size distribution, water chemistry and temperature [10,11]. Furthermore, the microstructure of CPB progressively changes during its transportation due to evolution of cement hydration product therein. Yield stress and plastic viscosity also increases where former is more sensitive to cement hydration [12]. CPBs are known to behave as non-Newtonian fluids, since shear stress at any point along the cross section of the pipe during flow depends on shear rate and time. Thus, the time-dependent rheological characterization of CPB is a matter of concern and is required to be estimated for various dosages of binder and SP. In this study, a unique experimental methodology is devised to estimate the effect of binder and SP dosages on time dependent rheological behaviour as well as that of hydration age on rheological parameters of CPB material developed from carbonate rich process tailings. Fig. 1 depicts the detailed methodology of mixing sequence and hydration process based on time scale for each combination of CPB sample for 15 min of hydration age. The experiments are conducted for hydration age of 15, 45, 75, 105, 135 and 165 min. For rheological test of CPB at hydration age of 45 min, the first 12 min mixing sequence remains the same. Then CPB sample is kept on rest up to 42 min then is loaded into the container from 42 to 43 min. Subsequently, sample is subjected to preshear from 43 to 44 min and finally loaded container is set with the rheometer and left undisturbed from 44 to 45. The similar procedure is followed for other hydration ages and only the duration of hydration age is increased after 12 min.

The paper elaborates on the experimental studies as discussed in Sections 3 and 4 and the results of statistical analyses in terms of yield stress, plastic viscosity and thixotropy as a function of hydration age, binder and SP dosages are outlined in Section 5.2. The study also finds that there are strong statistical relationships among the target rheological parameters and input variables such as hydration age, binder and SP dosages. The experimental results show that yield stress and thixotropy vary linearly with log of hydration age and plastic viscosity has the linear relationship with hydration age. SP dosages are found to be highly significant in reducing all these rheological properties. A fluidity index, κ evaluated based on binder and SP dosages, is found to have negative influence on yield stress, plastic viscosity and thixotropy. On the other hand hydration age has positive or increasing effect on rheological parameters. The multivariate analysis evaluates that κ is more significant than hydration age as far as rheological parameter of CPB is concerned. The above findings clearly demonstrate that CPB made with carbonate rich process tailings will require SP dosages to attain a desire rheological parameter for flow through pipe reticulation system. It is now possible to estimate a suitable SP and binder dosage from the developed statistical relationships for desire flow behaviour of CPB.

2. Materials and their characteristics

In the following, the properties of the materials used in this study such as tailings, binder, superplasticizer and water are described in details.

2.1. Tailings

The tailings samples under investigation have been collected from a dolostone hosted uranium ore processing mill located in South India. The tailing samples are stored in sealed plastic containers to prevent pore water loss and occurrence of oxidation prior to their subsequent usage in laboratory experiment. Before commencement of experiments, tailings samples are air dried and homogenized by thoroughly mixing and sub samples are prepared by coning and quartering. Particle size analysis is conducted using particle size analyzer (Mastersizer 2000 E Ver. 5.20, U.K) which reveals that 47% by weight of the tailings is finer than 20 μm (Fig. 2) and can be categorized as medium size grained particles as per Landriault's paste backfill material classification [7]. Since the majority of the particles are fine, the specific surface area of tailings determined using Automated Gas Sorption Analyzer (Autosorb-1, Quantachrome Instruments) is found to be on higher side and estimated to be 1515 m^2/kg.

Tailing are very close to well graded with an average coefficient of uniformity C_u as 9.44 and an average coefficient of curvature C_c of 0.96. The specific gravity of the tailings is found to be 2.83 and it is consistent with dolomite mineral's specific gravity. Hydraulic conductivity determined in accordance to ASTM standard is found to be 4.4×10^{-5} cm/sec. The maximum dry density of tailings is 1913 kg/m^3. Mineralogical analysis of the tailings by X-ray

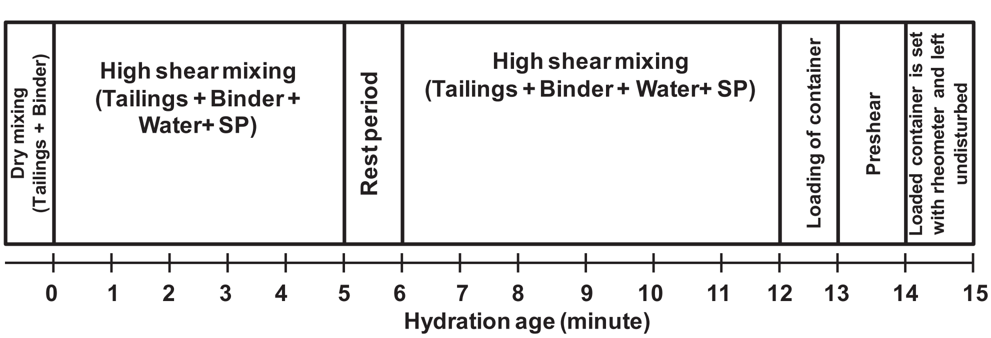

Fig. 1. Time scale for mixing and rheological experiment.