Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 23(2013) 3412−3420

Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Ultra fine grinding of silver plant tailings of refractory ore using vertical stirred media mill

O. CELEP, E. Y. YAZICI

UFG Group, Division of Mineral & Coal Processing, Department of Mining Engineering,
Karadeniz Technical University, Trabzon 61080, Turkiye

Received 21 March 2013; accepted 25 April 2013

Abstract: Ultra fine grinding of the plant tailings of a refractory silver ore was studied using a laboratory type vertical stirred media mill. Preliminary tests confirmed that ultra fine grinding substantially improves the extraction of silver from the tailings in cyanide leaching (i.e. 36% Ag extraction rate from the as-received tailings with d_{80} of 100 μm, c.f. 84% extraction rate after ultra fine grinding of the tailings with d_{80} of 1.2 μm). In the ultra fine grinding tests, the effects of ball diameter (2−4.5 mm), stirring speed (200−800 r/min) and ball charge ratio (50%−80%) on the fineness of grind (d_{80}, μm) were investigated through a Box−Behnken design. Increasing stirrer speed and ball charge ratio decreased fineness of grind while larger balls resulted in the coarser products. The tests demonstrated that a fineness of grind less than 5 μm can be achieved under suitable conditions. Analysis of stress intensity indicated an optimum range of stress intensity of $(0.8-2)\times10^{-3}$ N·m for all power inputs.

Key words: refractory ore tailings; stirred media mill; ultra fine grinding; experimental design; Box−Behnken design; stress intensity

1 Introduction

Refractory ores yield low extractions rates (i.e. <80%) of gold and silver in cyanide leaching even after grinding the ore down to −75 μm. These ores need a suitable pretreatment to achieve high gold and silver extractions rates during cyanidation [1]. Roasting [2], pressure oxidation [3], biooxidation [4,5] and ultra fine grinding [6] have been commercially practiced to enhance the gold/silver recoveries from refractory ores. The most common cause of refractoriness in gold and silver ores is the encapsulation of fine gold and silver particles within the mineral matrix in which these particles are not accessible to the lixiviating action of cyanide and oxygen [7]. If the encapsulated gold is 1−2 μm to approximately 20 μm in size, a desired degree of liberation can be suitably achieved by ultra fine grinding (UFG) without the need for costly and environmentally unfavorable chemical pretreatments [6,8].

In the last 20 years, the stirred media mills have been widely used for ultra fine grinding in different industrial fields such as mineral processing, plastic, ceramics, paint, food and cosmetic [9,10]. Vertimill®, Stirred Media Detritor (SMD®) and ISAMill® have been the most commonly used stirred media mills in mineral processing. The various types (e.g. glass, steel, ceramic, pebble etc.) and sizes (usually between 200 and 4000 μm) of grinding media were used depending on the feed size and feed material [11,12].

Various process parameters including stirrer speed, ball diameter, ball charge ratio and media density as well as mineral type affect the performance of a grinding process [11,13−18]. Many studies have been carried out to examine the operating parameters affecting the grinding performance of stirred media mills [15,16,19]. One classical factor at a time approach may fail in determining main and interaction effects together and optimising grinding parameters [20]. In this respect, the statistical experimental design methods can be suitably utilized to assess the main/interaction effects of parameters. Response surface methodology (RSM) is widely used since it combines mathematical and statistical methods [8,21−24]. Stress intensity analysis of grinding media based on grinding parameters such as stirrer speed, ball diameter and media height as well as slurry density, can be used to identify the optimum conditions at a given energy consumption [9,11].

Corresponding author: O. CELEP; Tel: +90-462-377-4118; Fax: +90-462-325-7405; E-mail: ocelep@ktu.edu.tr
DOI: 10.1016/S1003-6326(13)62882-4

Recently, application of ultra fine grinding using stirred media mills for the treatment of refractory gold and platinum ores prior to leaching, has been increased dramatically to improve the metal recoveries [25,26]. Old plant tailings, which were produced by conventional comminution circuits, may also contain substantial amount of precious metals. Chemical pretreatment of such tailings may fail to improve the extraction of precious metals [27]. Ultra fine grinding as a pretreatment step can be exploited as a potentially new approach for reprocessing of such plant tailings to recover contained metal/mineral values, which would also contribute to the conservation of natural resources.

In this study, the ultra fine grinding of the plant tailings of a refractory silver ore was studied to recover the contained silver in subsequent cyanidation. The effects of ball diameter (2−4.5 mm), stirring speed (200−800 r/min) and ball charge ratio (50%−80%) on the ultra fine grinding process were investigated using a laboratory type vertical stirred media mill. Response surface methodology, a three-level Box−Behnken design, was adopted to assess the effect of parameters on the response, i.e. particle size (d_{80}) of the product. Grinding efficiency in terms of stress number and intensity concept was also evaluated.

2 Materials and methods

2.1 Tailing sample and preliminary cyanidation tests

The plant tailings after cyanide leaching (d_{80}=100 μm) of a refractory silver ore were used in this work. The chemical composition of the ore sample was determined by wet chemical analysis method using ICP−AES (inductively coupled plasma−atomic emission spectroscopy), NAA (neutron activation analysis) after hot digestion in aqua regia for Au−Ag analysis and XRF analysis for major oxides. The tailing sample consisted of 50.7% SiO_2, 9.80% BaO, 7.30% Al_2O_3, 6.76% CaO and 5.72% Fe_2O_3. The sample was determined to be rich in silver containing 83 g/t Ag and 1.5 g/t Au. Earlier mineralogical studies on the tailings have shown that silver is present mainly in the form of native silver, pyrargyrite, tetrahedrite, argentite and proustite, which are closely associated with and/or encapsulated in other mineral phases, i.e. mainly barite, quartz, dolomite and feldspar [27]. Earlier studies have confirmed poor extraction of silver even after various chemical pretreatments of the tailings [27]. Details of the procedure for cyanide leaching and chemical analysis can be found elsewhere [28].

2.2 Ultra fine grinding tests

Ultra fine grinding experiments were performed using a laboratory scale pin-type vertical stirred media mill designed by the authors (Fig. 1) within a batch mode of operation. The technical features of the stirred media mill were described earlier by CELEP et al [8]. Energy consumptions in the grinding tests were measured using an electrical counter connected to the stirrer rotor. Micro-grinding ceramic beads (alumina-based zirconia toughened, DMM AZ 2000®) with different sizes (mean diameters of 2, 3.5 and 4.5 mm) were kindly provided by Dakot Milling Media (Pty) Ltd. (South Africa) and used as the grinding media. The beads had Al_2O_3 content of 80%, specific gravity (SG) of 3.75−3.80 and Vickers hardness (HV) of 1314 μm. Utilization of inert ceramic grinding media would avoid/limit adverse effects of steel media during leaching through formation and subsequent coating of iron oxide on mineral surfaces [29]. In the tests, the pulp density was kept at 24% (w/v). Analysis of particle size of the samples was carried out by the laser diffraction method using a Malvern Mastersizer 2000 MU. Particle size analysis was performed in four replicates (RSD: 0.71%) and the mean values were present in the results.

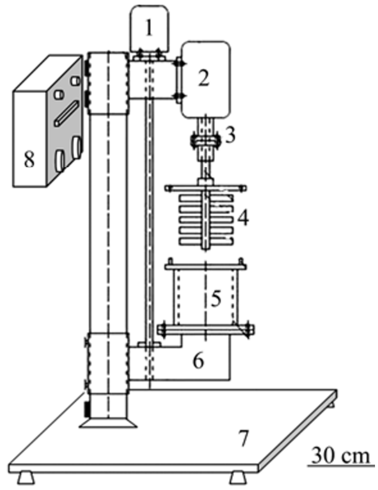

Fig. 1 Section drawing of stirred mill used in ultrafine grinding tests [8] (1—Motor for moving of grinding chamber; 2—Motor of stirring shaft; 3—Connection of motor and shaft; 4—Stirring pins; 5—Grinding chamber; 6—Moving table of stirred grinding chamber; 7—Stability table; 8—Control panel)

2.3 Experimental design

Response surface methodology (RSM) involves the utilization of mathematical and statistical techniques and allows the evaluation of contribution of several independent parameters (variables) on the response. A Box−Behnken design (BBD), essentially a type of RSM, has three levels, low (−1), center (0) and high (+1) as coded levels, with equally spaced intervals among these levels. Actual levels can be calculated by [30]

$$X_{\text{center}} = \frac{X_{\text{high}} - X_{\text{low}}}{2} \tag{1}$$