Effects of ball-to-mass ratio during mechanical activation on the structure and thermal behavior of Turkish lateritic nickel ore

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Abstract: In this study, lateritic nickel ore was activated mechanically in a planetary mill for different ball-to-mass ratios and the changes in the ore structure and thermal behavior of the ore were investigated by means of X-ray diffraction (XRD), scanning electron microscopy (SEM), particle size analysis and thermal analysis (TG-DTA). The results showed that particle size decreased and amorphization in the ore structure was occured with increment of the ball-to-mass ratio. The transformation of goethite to hematite in thermal behavior of laterite started to occur during mechanical activation.

Key words: Lateritic nickel ore, mechanical activation, thermal behavior.

Introduction

Nickel oxides (laterites) and nickel sulphides comprise the two types of ores used in industrial practice for nickel production. Today world nickel supply is covered predominantly by sulphide ores (60% against 40% by laterites. By taking into consideration that any additional nickel demand is expected to be mainly satisfied by mining of laterite deposits, the optimization of the metallurgical laterite processing methods constitutes a great challenge for the nickel industry and there is an increasing focus on the processing of the huge reserves of nickel-rich laterite ores due to declining global reserves of nickel sulphides (Zevgolis et al., 2000; King, 2005; Tunç et al., 2012a)

Nickel laterites are derived from ultramafic rocks and contain economically exploitable reserves of nickel and commonly cobalt. The deposits are developed on olivine-bearing ultramafic rocks, mainly dunite and olivine-pyroxene peridotite and their serpentinezed equivalents [Brant, 1998]. The oxidic ores of nickel are formed by a chemical concentration process that occurs as a result of the lateritic weathering of peridotite rock. Peridotite consists mainly of olivine, a magnesium iron silicate containing up to 0.3% nickel. In many rocks the peridotite has been altered to serpentine, a hydrated magnesium silicate, prior to exposure to weathering. Olivine and serpentine are decomposed by groundwater containing carbon dioxide to form soluble magnesium, iron and nickel. The iron rapidly oxidizes in contact with air and precipitates by hydrolysis to form goethite and hematite, which remain near the surface of the deposit (Roorda et al., 1973).

Extractive metallurgy of nickel is dependent on the type of ore body. Although recovery of nickel from sulfide ores is based on only pyrometallurgical methods, flow-sheets of nickel extraction from laterites are based on both pyrometallurgical and hydrometallurgical methods. Hydrometallurgical or combination of pyrometallurgical and hydrometallurgical treatments of lateritic ores rely on the homogeneous chemical and mineralogical distributions within the laterites. In laterites, nickel is mainly present in goethite, serpentine, smectite and in manganese oxides together with cobalt. Since cobalt is associated with nickel, processes to extract nickel are also applicable to extract cobalt. Therefore hydrometallurgical treatments are based on extracting nickel and cobalt from iron, magnesium and manganese oxides, based on leaching procedures (Büyükakıncı, 2008).

The mechanical activation of minerals makes it possible to reduce their decomposition temperature or causes such a degree of disordering that the thermal activation may be omitted entirely. In this process, the complex influence of surface and bulk properties occurs. The mineral activation leads to a positive influence on the reaction kinetics, an increase in surface area and further phenomena. Mechanical activation by high energy milling is an innovative procedure that improves the efficiency of mineral processing because of several factors, most importantly the formation of new surfaces and the creation of lattice defects. High energy ball milling can induce, at room temperature, some chemical reactions that normally occur at very high temperatures (Balaz, 2008; Tromans et al., 2001; Apaydin et al., 2011).

In this study, the effects of ball-to-mass ratio during mechanical activation on the structure and thermal behavior of a Turkish lateritic nickel ore were investigated with X-ray diffraction (XRD), particle size analysis, scanning electron microscopy (SEM) and thermal analysis (TG/DTA).

Materials and Method

Lateritic nickel ore was obtained from Manisa-Gördes (Turkey). The ore was ground to a size of <100 μm. The mechanical activation of lateritic nickel ore was performed in a Planetary Mono Mill Pulverisette 6 under the following conditions: the weight and diameter of tungsten carbide (WC) balls were 200 g and 10 mm respectively; the grinding bowl was 250 mL WC; the grinding times was 30 min; the speed of the main disk was 600 rev.min-1; the grinding process was dry. Ball-to-mass ratios during mechanical activation were 10, 20, 30 and 40.

X-ray diffraction analysis was performed using a Rigaku Ultima X-ray diffractometer and Cu Kα radiation. A JEOL 6060 LV scanning electron microscope (SEM) was used for morphological analysis of the non-activated and activated samples. DTA was performed using TA Instruments SDTQ 600 at heating rate of 10°C.min-1 under atmospheric conditions and Mikrotrac S3500 was used for particle size distribution analysis.

Results and Discussion

X-ray diffraction patterns of non-activated laterite and activated with different ball-to-mass ratios are given in Figure 1. Quartz and goethite are the major phases while hematite presents as minor phase. When laterite was subjected to mechanical activation for different ball-to-mass ratios during milling, peak broadening and decreasing of intensity occurred. This fact is the result of crystal lattice imperfections and disorderings. Crystalline size becomes smaller than about one micron by mechanical activation. During high-energy milling, the size of crystals decreased to some critical values. Further energy supply to these crystals of limiting size causes further deformation of crystals, energy accumulation in the volume or at the surface of crystals and subsequently amorphization. There is not only one effect occurring during the milling process. Because of the contact between powder – ball and attrition between powder-ball-bowl, local temperatures may be increase for higher rev (Tunç et al., 2012a; Balaz, 2000; Tunç et al., 2012b).

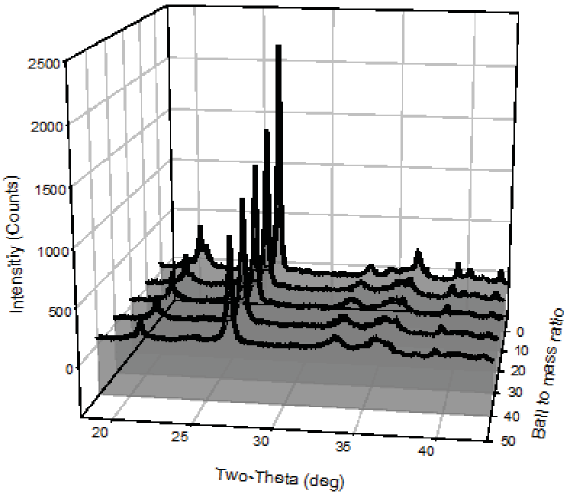

Figure 1. X-ray diffraction patterns of non-activated and activated laterite ore with different ball-to-mass ratios

Scanning electron micrographs (SEM) and particles size analysis of the samples were given in Figure 2-4. It was clear that the particle size decreased during mechanical activation. SEM analysis is in good agreement with particle size distribution data, given in Table 1. Defining of particle size distribution by using three percentiles is common practice. These are the cumulative distributions of particle size correspond to 10%, 50%, 90% and specified as d_{10}, d_{50}, d_{90}. They are taken directly from mass-based cumulative particle size distribution (German, 2007). Mechanical activation results in smaller particle than the non-activated one when focused on d_{90} cumulative distribution, but when d_{50} column is taken into account, the particles become larger. Increases in the particle size with mechanical activation may be due to the agglomeration of the particles. When the particle is milled, its surface area increased because of the crushing and forming new surfaces become more reactive.

Table 1. Particle size analysis of non-activated and activated laterite samples

Ball-to-mass ratio	d_{10} (µm)	d_{50}(µm)	d_{90} (µm)
Non-activated	1,103	35,65	120,20
10	0,635	2,711	36,67
20	0,646	3,320	33,49
30	0,644	3,600	30,80
40	0,668	5,781	32,68

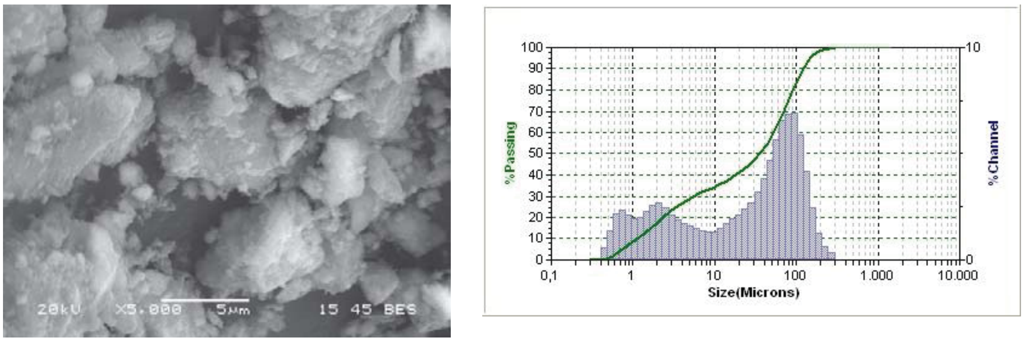

Figure 2. SEM micrograph and particle size analysis of non-activated ore

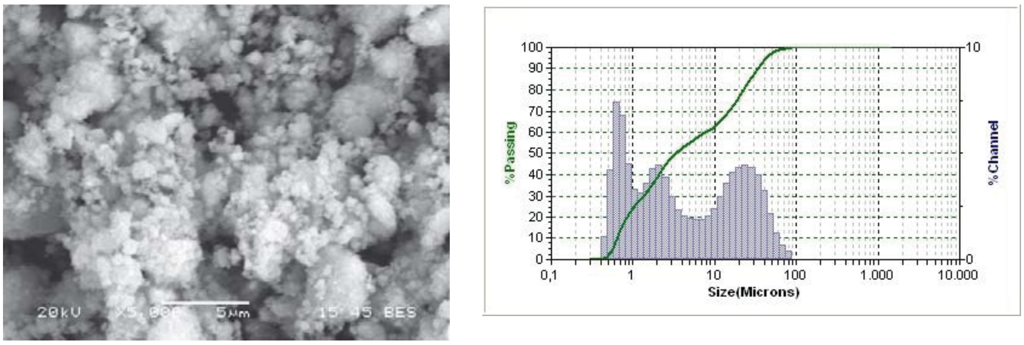

Figure 3. SEM micrograph and particle size analysis of activated ore (ball-to-mass ratio: 20)

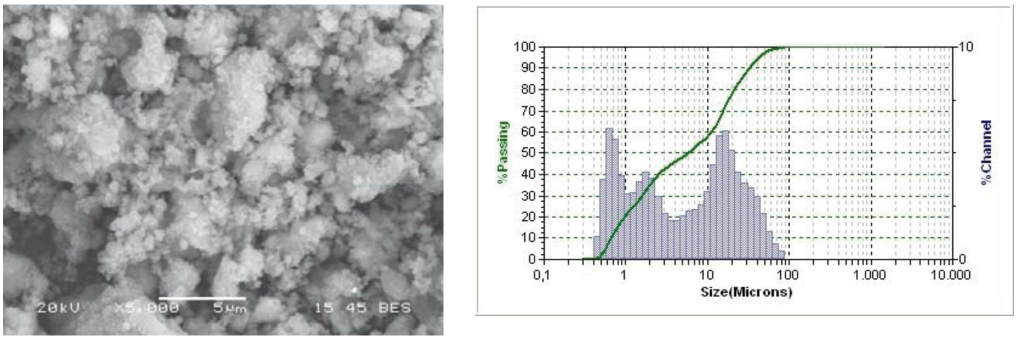

Figure 4. SEM micrograph and particle size analysis of activated (ball-to-mass ratio: 40)

Thermal analysis (TG/DTA) of the non-activated and activated laterite with different ball-to-mass ratios are given in Figure 5 and 6. For the non-activated lateritic nickel ore, the weight losses in two steps exist at 120°C and 280°C, belonging to evaporation of humadity and dehydroxylation of goethite into hematite respectively. The temperature of dehydroxylation for pure goethite varied between 274 and 305°C, depending on particle size and crystallinity. O'Connor et al.(2006) stated that the transformation of goethite to hematite occurred between 210 and 370°C in limonitic laterite. Pickles (2004) also stated that the goethite – hematite transformation occurred after 250°C in limonitic laterite. Mechanical activation resulted in disappearing the second endothermic peak corresponding to transformation. From these results it can be said that goethite transformation into hematite needs lower energy than the original one for activated samples because of the accumulated energy from mechanical activation and there is a probability for transformation which occur during milling.

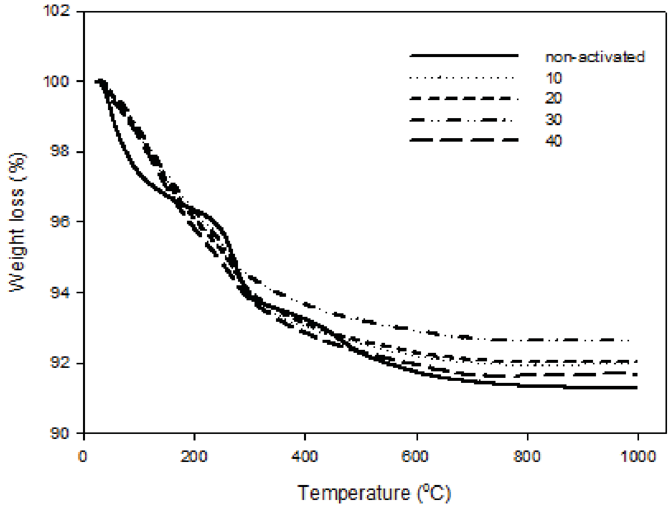

Figure 5. Thermogravimetric analysis (TG) of the samples

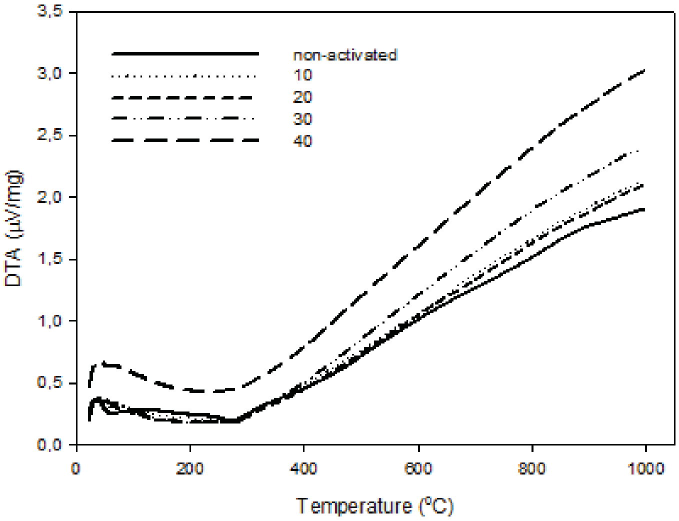

Figure 6. Differantial thermal analysis (DTA) of the samples

Conclusions

Increasing in ball-to-mass ratio during mechanical activation caused amorphization and structural disordering in laterite. Particle size of the ore was decreased. Dehydroxylation reaction, which is transformation of goethite to hematite, occurred during milling and the peak of dehydroxylation in thermal analysis (DTA) disappeared, due to the structural disordering in laterite.

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