Influence of Coal and Reduction Parameters on Lateritic Limonite Type Rock in Producing Nugget Iron for Thin-wall Ductile Iron Material

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ABSTRACT

Finding iron sources from other ores is important because of the depletion of iron ore. One such source is lateritic rocks. Lateritic rocks are a nickel source, but owing to their high iron content, they are promoted as an iron source. This research was conducted to investigate the effect of reduction parameters on lateritic rock behaviour. Lateritic limonite rock is used. Process parameters include particle size, temperature, holding time and ratio of carbon. Particle size is varied in 120, 170, 200 and 270 meshes. Temperatures are 600, 800, 1000, 1100 and 1200°C. Holding times used are 60 and 90 minutes. The variable ratios of carbon to ore are 1:1, 2:1, and 3:1. The results show that among all the parameters, temperature has a significant effect and holding time displays the weakest effect.

INTRODUCTION

Lateritic rocks consist of two types of ore. The upper layer is known as limonite, and the lower layer is known as saprolite. Limonite has a higher iron and lower nickel content compared to saprolite. This condition enables lateritic rocks to be iron sources (Soedarsono et al., 2012; 2014a). The refining processes of both metals tend to be similar. In producing iron, the direct reduction process (DRP) is an important stage and involves several parameters. Paramguru et al. (1997) and
Sohn et al. (2005) supported this statement, especially when there were many types of ores that could be used as the source (Soedarsono et al., 2012). Parameters involve in the DRP are particle size, temperature, time and carbon content.

When studying particle size, Soedarsono et al. (2014a; 2014b) found that before roasting a 100 mesh particle size had the highest iron content. They also concluded that particle sizes do not have a specific relationship with Fe content. Soedarsono et al. (2013) found that roasting process increases the Fe content. The highest content was found in 170 meshes, while the highest increase was in 120 meshes. Standish et al. (1991) reported that particle size, although unstable in the roasting process was an important parameter. Their research found that in a microwave heating process a smaller size of alumina was easier to roast, while the opposite applied to magnetite.

Reduction temperature has the greatest influence among all parameters. Zhu et al. (2012) concluded that high reduction temperatures increased nickel content as result of the wustite higher reduction rate to form iron and realising nickel from teanite. Kawigraha et al. (2013) found that there was a temperature effect on iron phases in reduced pellets. Valix and Cheung (2007) stated that the optimum reduction process for limonite was at a temperature of 600°C, and for saprolite, it was 800°C. Kukura et al. (1979) on the other hand, reported that goethite dehydroxylation at 400°C increased the open areas of the mineral structure. This caused instability of the iron matrix. Zevgolis et al. (2010) found that temperatures higher than 400°C decreased the open areas. Guo et al. (2011) stated that the optimum reduction temperature for nickel from limonite was 1050°C. De Graaf (1979), O’Connor et al. (2006), and Schulz et al. (1980) recorded that reduction time affected reduction, especially at high temperatures. Li et al. (2011) found that nickel content increased with reduction process time owing to an ongoing three stages process. Zhu et al. (2012) found that the optimum process time for a 40% saprolite, 6% additive, 5% coal compound, at 1100°C was 60 minutes.

A study of carbon content by Chang et al. (2008) showed that iron phase transformation depended on the carbon content. Soedarsono et al. (2014a) found that increasing the carbon content under certain conditions increased the gasification rate during direct reduction. This increase of gasification rate resulted in increased Fe formation. Lack of coal during the reduction process resulted in oxidation of iron phases (Usui et al., 2004). Chander and Sharma (2007) showed that iron reduction to hematite slowed the nickel diffusion process, while that of wustite accelerated it.

The research reported here was conducted to investigate the effects of particle size, reduction temperature, reduction time and coal ratio on the lateritic limonite rocks reduction process.

**EXPERIMENTAL METHOD**

Research was carried out in the laboratory scale. Lateritic rocks of limonite type came from Pomalaa, Indonesia. Coal was used as the carbon source. Rocks were crushed and sieved to particle sizes of 120, 170, 200, and 270 meshes. The coal size was 70 mesh.

The processes were crushing, sieving, drying, mixing, compaction, and reduction. The drying temperature was 110°C for about 24 hours. The mixture was
compacted to a cylinder briquette of 22 mm in diameter and about 16 mm in height using pressure of 150 bar. Reduction parameters were varied to analyse their effects. The reduction process parameters are displayed in Table 1.

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<th>TABLE 1. PROCESS PARAMETER.</th>
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<td>Particle size mesh</td>
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<tr>
<td>Reduction temperature °C</td>
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<td>Holding time minutes</td>
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<td>Ratio of coal to ore</td>
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The analysis methods were simultaneous thermal analysis (STA), energy-dispersive X-ray (EDX) analysis and X-ray diffraction (XRD). STA tests were based on ASTM E 967 in the temperature range 25-1000°C.

RESULTS AND DISCUSSION

The EDX analysis result (Table 2) show the presence of magnesium (Mg), aluminium (Al), silicon (Si), iron (Fe) and nickel (Ni) in the ore chemical composition. The iron content is 34.04% while that of nickel is only 1.23%. Compared to the standard released by Crawford (1972), the lateritic ores are categorised as limonite type.

<table>
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<th>TABLE 2. CHEMICAL COMPOSITION OF LATERITIC ORES.</th>
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<td>Ni%</td>
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<td>Crawford (1972)</td>
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<td>Limonite</td>
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<td>Saprolite</td>
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<td>Samples</td>
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The STA curve (Fig. 1-a) shows that there are three endothermic reactions occurring. The first endothermic reaction happens at 85°C followed by reaction at 300 and 631°C. The first reaction is related to elimination of free water. The second reaction involves de-hydroxylation of goethite. Queneau (1971) states that de-hydroxylation of goethite happens at 385°C. The third reaction is due to de-hydroxylation of serpentine to lizardite. This process is in accordance with the conclusion of Rizov (2012) and confirms the classification as limonite type. The XRD results (Fig. 1-b) show the presence of silica, goethite, halloysite, and fayalite.
Figure 1. Analysis results of lateritic ore.

TG: Thermogravimetric  DSC: Differential Scanning Calorimetric

Figure 2. STA curve for coal.

The STA results for coal (Fig. 2) reveal the presence of moisture, volatile matter and fixed carbon. Moisture content is 10.81%, volatile matter is 8.52% and fixed carbon is 40.96%.

The XRD results for the effects of particle size (Fig. 3-a) show phases changing. Goethite disappears but silica, halloysite and fayalite increase. New peaks appear which means new phases are formed. They are magnetite, tetrataenite and new fayalite. Although magnetite tends to form fayalite, it is still present owing to the higher reduction rate of hematite compared to fayalite. Hematite is formed from dehydroxylation of goethite. The magnetite intensity tends to increase as the particle size becomes finer. Formation of tetrataenite detains magnetite reduction to form wustite. The EDX analysis results for iron (Fig. 4-a) show that iron content increased the reduction process. The highest iron content after reduction is for the 170 mesh (16.3%), while the lowest is for 120 mesh (1.1%). Iron contents increase between 9 and 15%. The amount of fayalite and tetrataenite also tend to increase as particle size decreases.

Reduction temperatures are closely related to phase changes. The XRD results (Fig. 4-b) show this. At 600°C, halloysite, silica, magnetite and fayalite are formed. At 800°C, in addition to the four phases, tetrataenite and enstatite are also formed. Forsterite completes the existing phases at 1000°C. The phases return to those at 600°C with the additional presence of tetrataenite at reduction temperatures of 1100°C and 1200°C. The amounts of magnetite, fayalite and tetrataenite phases tend to increase as the reduction temperature increases. For particle sizes, the reduction temperature also tends to enrich iron content (Fig. 4-b). The highest iron content is present at 800°C (17%) while the lowest is at 1000°C (3%). The iron
content reaches its maximum at 800°C owing to enstatite formation. After that, the iron content tends to be stable as the reduction temperature increases with the content changing between 3 and 17%.

The holding time in the reduction process does not show any significant influence. XRD results (Fig. 3-c) show the same phases for all holding times. EDX analysis result (Fig. 4-c) show an increase in iron content after reduction. Iron contents increase by about 16.30 to 16.50%. Differences of carbon content between holding times are 0.2%.

The amount of magnetite, fayalite and tetrataenite increase as the ore to coal ratio increases (Fig. 3-d). The iron content also increases after reduction but a special case happens at a ratio 2 to 1. At this ratio, iron content only increases by 11.7%, while at 1:1 and 3:1, it increases by 16%. The highest increase is by 16.3% at a ratio of 1:1. The highest difference in iron content between ratios is 4%.
Compared to previous research by Soedarsono et al. (2014a; 2014b), the present research found a relationship between particle size and iron content. This research also found the highest iron content was in a particle size of 170 mesh, which confirms the work of Soedarsono et al. (2013). This research has a different finding from that of Standish et al. (1991). As concluded by Kawigraha et al. (2013), reduction temperatures play an important role in phase formation. Ore used in this research was classified as limonite type. However, the maximum iron content was reached at a reduction temperature of 800°C, which is mentioned in Valix and Cheung (2007) as the optimum temperature for saprolite ore. Instability of phases occurred as mentioned by Kukura et al. (1979). Regarding the holding time, the work of Yuan et al. (2006) confirmed that changes do not occur in a 90 minute holding time. As mentioned by Soedarsono et al. (2014a) the ratio of ore to coal is important for sustainability of the reduction process.

CONCLUSION

The main conclusions of this research are as follows:
- The lateritic rocks used were classified as limonite type, but several results represented saprolite characteristic;
- The reduction process of lateritic rock enriched the iron content in the form of iron oxides;
- Particle size and reduction temperature played important roles in the reduction process;
- Temperature was the most significant parameter;
- The greatest increase of iron content (17.2%) occurred at 800°C;
- Optimum particle size was 170 mesh;
- The ratio of carbon to ore that give the highest iron content was 1:1;
- Holding times did not have a significant effect on iron content.

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REFERENCES


