Effect of temperature on porosity of iron ore sinter with biochar derived from EFB

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Abstract. In this research, the replacement of fossil fuel energy (coke) with oil palm empty fruit bunch as a potential energy in sintering of iron ore was investigated. Carbon derived biomass has been produced by using oil palm empty fruit bunch by heat treatment process. In the present investigation, sintering process was carried out by heating the mixed iron ore and biochar at various temperatures. The apparent density and porosity for iron sinter show a significant increase and gradual decrement as the temperature increase, respectively. The porosity of iron sinter shows a gradual decrement from 950 ºC to 1050 ºC but up to 1150 ºC it shows a significant decrement about 44%. Inferring to the micrograph, the agglomeration and assimilation of sinter at high temperature is better compared with low sintering temperature.

1. Introduction

Depletion of high grade iron ore happened throughout the world [1] and Malaysia is a renowned resource on low grade iron ore. The usage of low grade iron for sintering process has been continuing due to abundance of low grade iron ore [2]. Sinter is the main iron-bearing burden for the blast furnace and its production is based on coke breeze as a source of fuel.

Currently, coke was used as main fuel in sintering of iron ore but there is some problems arises from this application such as energy consumption during the production of coke. In order to mitigate these problems, biomass can be a probable source of energy to be utilized to replace coke [3]. The potential alternative energy that can substitute fossil fuels is biomass [4]-[8]. In order to highlight the problems in this steel industry, usage of biomass as energy fuel is an interesting solution for iron making, so many different ways of its usage should be tried to reduce the energy consumption and CO₂ emissions [9]. A biomass is considered carbon neutral and can be used as a source of heat and as reducing agent for iron reduction process.

In iron making industry, iron sinter is one type of raw materials to be charged into blast furnace. Sintering is the process of converting iron ore fines into coarse agglomerate granules product due to the partial fusion and coalescence bonding for blast furnace usage [10]-[11]. In blast furnace operation, the structure produced from sintering process seize a vital factor that give effect to the strength and reducibility of sinter [12]. Porosity is one of the vital component in physical of property of iron ore. By having high porosity provides large contact area for reducing gas to facilitate into the interior of the lump ore [13]. The mechanical properties of final iron sinter could be influenced by the fusion phase produced during sintering process in which the sinter must have a good strength and porosity [14]. In this work, the effects of oil palm empty fruit bunch (OPEFB) addition on the
sintering of low-grade iron ore were investigated with regards to the density and porosity of iron sinter.

2. Experimental procedures

2.1. Materials
In this experiment, an iron ore taken from mining site in Bahau, Negeri Sembilan was selected as raw material for sintering. The ore then is crushed and ground to get fine particle. The chemical compositions of iron ore is shown in table 1. OPEFB was supplied by local palm oil mill and used as the source of material to produce biochar. Chemical composition of OPEFB is given in table 2. In order to reduce the melting temperature of sinter granules the limestone was added to the mix of biochar and iron ore.

Biochar making was carried out by putting OPEFB in an electric furnace under vacuum atmosphere for 10 minutes to remove the present of oxygen. The temperature was increased to 450°C at a heating rate of 10°C/min, and held for 30 minutes to allow complete production of biochar. In order to produce a granulated green sample, the iron ore, biochar and limestone were mixed by adding water binder and placed in a ceramic bowl. The granulated green sample was dried at 100°C for 24 hours to remove the water.

2.2 Experimental Method
Sintering process was conducted by putting the granulated green sample in an electric furnace at various temperatures from 950°C to 1150°C with heating rate of 10°C/min and holding time of 30 minutes. The physical properties of iron sinter such as apparent density and porosity was examined. The morphology of iron sinter was also observed by using FESEM. The schematic diagram of furnace for sintering and biochar making are shown in figure 1.

Table 1. Elemental composition of used iron ore (Bahau, Negeri Sembilan).

| Compound | Fe   | Al  | Mg  | Si  | K   | Ti  | V   | Cr  | Mn  | Zr  |
|----------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Percentage | 51.92 | 9.202 | 0.436 | 14.87 | 0.06 | 0.516 | 0.064 | 0.058 | 0.226 | 0.016 |

Table 2. Elemental composition of OPEFB.

| Proximate analysis | wt% | Ultimate analysis | wt% |
|--------------------|------|-------------------|------|
| Moisture           | 6.8  | Carbon            | 45.64 |
| Volatile matter    | 83.94| Hydrogen          | 6.19  |
| Fixed carbon       | 8.98 | Oxygen            | 48.17 |
| Ash                | 7.08 | Nitrogen          | 0.35  |
3. Results and Discussion

The figure 2 shows the apparent density and porosity on the iron sinter with 10% content of biochar. In this case, the apparent density for iron sinter shows significant increase as the temperature increase from 950°C to 1150°C. The porosity of iron sinter shows a gradual decrement from 950 °C to 1050 °C but up to 1150 °C it shows a significant decrement about 44%. This result is in line with the porosity shown in figure 2 in which apparent density high could produce dense and compact iron sinter.
Morphology of iron sinter for 10% biochar content with different sintering temperature (a) 950°C, (b) 1050°C, and (c) 1150°C are shown in figure 2. Noticeable granules have been produced at figure 3(b) and (c) with dense sinter compared with figure 3(a). The micrograph in figure 3 (a), (b) and (c) in line with the porosity and density shown in figure 2. At high temperature shows higher agglomeration and assimilation of sinter mixtures compared to low temperatures. Reshaping of irregular shape pores into more rounded shape indicates the combination of small pores to form a reduced number of larger pores as shown in figure 3(b).

**Figure 2.** Apparent density and porosity of the iron sinter with 10% content of biochar.

**Figure 3.** Morphology of iron sinter for 10% biochar content with different sintering temperature (a) 950°C (b) 1050°C (c) 1150°C.
4. Conclusion
In conclusion, the apparent density for iron sinter shows a significant increase as the temperature increase from 950ºC to 1150ºC. Morphology of the sinter revealed that the dense iron sinter has been produced in terms of agglomeration and coalescence of sinter particles at high sintering temperature. In summary, it shows that the usage of carbon derived biomass can produced compact and dense iron sinter. Thus the usage of biochar from oil palm empty fruit bunch could be an alternative energy source for sintering of low grade iron ore for iron making that could lead to the improvement of density and porosity of iron sinter.

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