

WASTE PLASTIC AS AN ADDITIONAL RAW MATERIAL OF METALLURGICAL COKE TO PRODUCE HYDROGEN AS BY-PRODUCT

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INTRODUCTION

The main CO₂ source in the ore-based carbon steel manufacture is coal to be processed into coke acting as the main reducing agent in the blast furnace. The CO₂ avoidance must be executed in many different sequential and simultaneous ways, because there is not a single solution to drastically reduce CO₂ emissions (Emi 2004 and Heino 2006). Because of the limited source of coking coal, new methods must be found to substitute the virgin raw material with appropriate secondary or bio based compounds.

Besides concentrating on the main properties of coke, strength and reactivity, the coking process requires also sustainable management of the coke oven gases, H₂ ~58.5 vol-% as the main utilisable components. The coke oven gas is typically used as an energy source. This can also be done also by using low grade biomass and biofuels dried with low temperature extra heat from integrated steel plants otherwise wasted to natural waters (Heino 2006). Hydrogen use in fuel cell vehicles is one of the best options in the near future (Turpeinen et al. 2008).

Without large investments costs to an extra treatment plant waste plastic can be processed in coke ovens (Figure 1) simultaneous with coal to act as a structural support, carbon based reductant, fuel, and carburization agent for the hot iron metal in the blast furnace and also to hydrogen production (Yonesawa 2008).

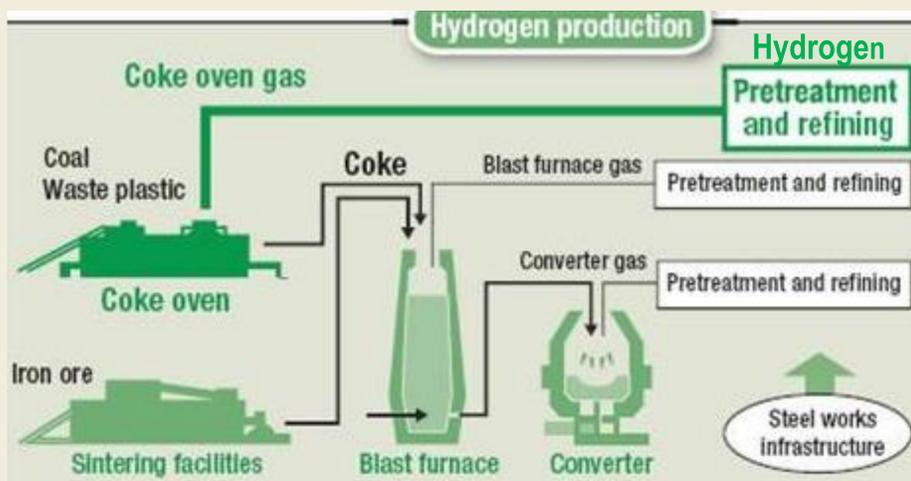


Figure 1. Production of hydrogen from coke oven gas (Modified from Yonesawa 2008).

Currently, hydrogen is primarily used in the chemical industry, but in the near future it will have a significant role as a fuel. Fuel cells are seen as a potentially huge market for H₂, and environmentally friendly technique as producing only water. Coke oven gas containing primary H₂ has a substantial potential as a H₂ source. The share of H₂ in the product gas is even expected to increase by adding plastic into coking process.

In order to obtain high purity hydrogen, separation of H₂ from the product gas mixture is necessary. Membrane technology is an emerging separation method that exhibits attractive merits over e.g. adsorption as it offers high energy efficiency, ease of operation and environmental friendliness (Adhikari 2006).

EXPERIMENTAL

The metallurgical coke was prepared in 9 coke ovens (Figure 2) by coking 3 coals (RI), (BU) and (EV) used in Ruukki Raahe, Finland without and with varying amounts of most widely used plastic: polyethylene (PE), (C₂H₄)_n. In the coking process samples were heated to 1200 °C and cooled to room temperature. Coking time was 16 h and quenching time 6 h.



Figure 2. Laboratory coke ovens.

In order to evaluate and define the maximum limit of the amount of plastic without any harmful effects the coke compression strength was measured (Zwick 2000). An image analysis by optical microscopy was performed to study the textures and pores of coke (Makkonen et al. 2009). The ASAP 2020 pore size analyser was used to measure the porosity and the BET surface area of the coke (Webb & Orr 1997).

In the first part of the trials coke was prepared using three coals (RI, BU and EV) with and without varying amounts of PE plastic. Based on the cold compression strength results of the first part test trials, the RI coal with PE plastics was used in the second part of laboratory experiments.

The duplicate cold compression strength results of coke made using the RI coal with varying amounts (0%–12.5%) of PE plastic are presented in Figure 3. Only a very slight change in cold compression strength results was observed from 0 to 5% PE plastic addition to the RI coal. When the amount of PE plastic in the RI coal is more than 6%, the cold compression strength decrease is very dramatic.

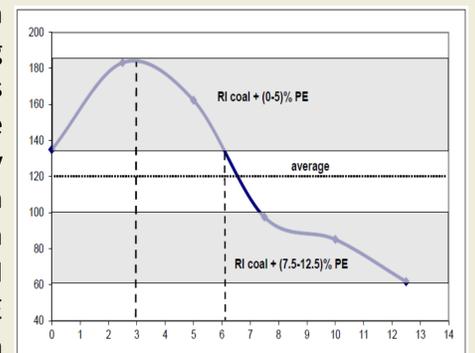


Figure 3. Cold compression strength (kN/m²) of coke as a function of PE plastic addition (%) in the RI coal.

Preliminary image analysis observations show that the amount of mosaic texture rises when PE plastic is added in the RI coal, and vice versa the amount of isotropic texture drops. The amount of banded texture varies between c. 20–26% and it seems to be more or less stable regardless of the PE plastic addition to RI coal.

The macro pores in coke samples made using PE plastic have a more rounded (isometric) shape than in the 100% coal-based coke. Coke pore volume and BET area in pores less than 78.8 nm diameter increase when the amount of PE plastics in the RI coal is added.

DISCUSSION AND CONCLUSIONS

It was established (Figure 3) that the addition of 6% of PE in the RI coal will result in the same strength value as it was measured in the coke without PE. We suggested that the addition of 3–5% PE can be reasonable as it will decrease virgin coal consumption and will not detract from coke strength.

Addition of plastics below 5% results in the increase of mosaic texture at the expense of isotropic texture and compensates for the weakening effect of increased porosity. The argumentation is confirmed also by the observations by Sharma et al. (2005) and Cheng (2001).

Rounded macro pores observed in texture analysis, decrease the weakening effect (Ueoka et al. 2006). In Nomura et al. (2003) test trials 2% addition of PE plastic slightly increased the strength of the plastic in a large-scale coke oven trials. The effect of PE plastic addition on porosity by Nomura et al. (2003) was similar than in our trials.

In order to obtain high purity hydrogen for use i.e. in fuel cells membrane technology is one of the best choices because of low energy consumption, ease of operation and environmental friendliness.

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