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Coal Plasticity at High Heating Rates and Temperatures

Seventh Technical Progress Report

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Abstract

Using a high temperature plastometer with a new cone-shaped shearing disk, the effect of shear rate (γ_R) on the apparent viscosity of softened coal was studied. For γ_R from 2.01 s^{-1} to 10.7 s^{-1} , no shear rate effect on the viscosity of Pittsburgh No. 8 high volatile bituminous coal was observed. Three other coals, each of different ranks ranging from high volatile bituminous to low volatile bituminous, were also studied. Although lower in tar and extractable yields than high volatile bituminous coals, medium and low volatile bituminous coals were found to be very plastic. Their good plastic behavior is therefore hypothesized to arise from their ability to generate higher molecular weight liquid fragments ("macrometaplast") which are not represented by tar and extractable yields.

1. Introduction

A high temperature plastometer with a new cone-shaped shearing disk is being used to obtain plasticity data for different coals. Effects of shear rate on coal plasticity were studied by performing experiments on Pittsburgh No. 8 high volatile bituminous coal at various shear rates. Effects of coal-type on coal plasticity were studied by performing experiments on three other coals, each of different ranks ranging from high volatile bituminous (hvb) to medium volatile bituminous (mvb), and to low volatile bituminous (lvb).

2. Shear Rate Effect on Coal Plasticity

The coal selected for this experiment was Pittsburgh No. 8 hvb, a highly softening coal. The plastometer's shear rate (γ_R) was varied from 2.01 s^{-1} to 10.7 s^{-1} . The heating rate used was 400 K/s , and the holding temperature was 1098 K . The temperature-time history is shown in Figure 1.

For γ_R from 2.01 s^{-1} to 10.66 s^{-1} , no shear rate effect on the apparent viscosity of Pittsburgh No. 8 hvb coal was observed. There was no effect on the plastic period, the viscosity at various times and temperatures, and the maximum plasticity. Figure 2 illustrates the plasticity vs. time curves of Pittsburgh No. 8 hvb at different shear rates. Figure 3 shows the viscosity of Pittsburgh No. 8 hvb at different times and temperatures to be independent of shear rate.

Figure 1: Temperature-time History

Figure 2: Viscosity vs. Time
Pittsburgh No. 8 hvb

**Figure 3: Viscosity vs. Shear Rate
of Pittsburgh No. 8 HVB**

In light of the observation that coal plasticity is independent of shear rate over the range studied, the lower shear rate (2.01 s^{-1}) has been selected as the standard operating shear rate of the plastometer.

This shear rate was selected to avoid overloading the torque transducer which has a maximum torque limit at $70.6 \cdot 10^{-3} \text{ N}\cdot\text{m}$ (S. Himmelstein and Company, 1983). Use of a higher shear rate will result in the maximum torque limit of the transducer being exceeded, especially at the beginning of a run when the plastometer is shearing solid coal particles and at the end of a run when the plastometer is shearing solid coke residues.

3. Plasticity Results of Different Coal Types

Argonne premium coals samples were used for these experiments. The coals used were Illinois No. 6 (hvb), Upper Freeport (mvb), and Pocahontas No. 3 (lvb). The tar and extractable yield data for these coals are available from the literature (Snape and Bartle, 1991 and Niksa, 1991). In addition, some structural data such as O/C and H/C ratios and fraction of labile bridges are also available (Niksa, 1991).

The samples were heated rapidly (400 K/s) to the holding temperature of 1098 K . A representative temperature-time history is shown in Figure 1. The shear rate used was 2.01 s^{-1} , and experiments were done under vacuum and under 1 atm . All three coals were found to be very plastic. The maximum plasticity ranged from approximately $1700 \text{ Pa}\cdot\text{s}$ to $7500 \text{ Pa}\cdot\text{s}$, with Illinois No. 6 coal

exhibiting the lowest viscosity. The plastic period (the period in which the viscosity is below 50000 Pa•s) ranged from 1.4 s for Illinois No. 6 and Pocahontas No. 3 to 1.9 s for Upper Freeport.

The plasticity curves for each coal are shown in Figures 4 a, b, and c. The maximum plasticity and plastic period of the three different coals are shown in Figures 5 a and b.

4. Discussion of Plasticity Results

From replicate runs and previous calibration results, the maximum noise from the plastometer is approximately $1 \cdot 10^{-4}$ N•m or 300 Pa•s (Gerjarusak et al., 1991). Therefore, the observed maximum plasticity data show a trend in which at vacuum and also at 1 atm the hvb coal has the lowest viscosity reading when compared to the mvb coal which has a lower viscosity reading than the lvb coal (Figure 5 a).

From the present data, however, there is no evidence for a continuous increase (or decrease) in the plastic period with increasing coal ranks (Figure 5 b). From replicate runs and the sampling interval of the digital recorder, the maximum error in measuring the plastic period is about 0.1 s. With the plastic period ranging from 1.4 s to 1.9 s, the mvb coal exhibits the longest plastic period when compared to the hvb and mvb coals, which have the same plastic periods (Figure 5 b).

Figure 4a: Plasticity Curves for HVB Coal (Illinois No. 6)

Figure 4b: Plasticity Curves for MVB Coal (Upper Freeport)

Figure 4c: Plasticity Curves for LVB Coal (Pocahontas No. 3)

Figure 5 a: Maximum Plasticity of Different Coals

Figure 5 b: Plastic Period of Different Coals

At present, it is uncertain whether a trend exists for the plastic behavior of coals of different ranks. The strong plasticity exhibited by the mvb and lvb coals is interesting. In general, a typical hvb coal (Illinois No. 6 or Pittsburgh No. 8) has a maximum tar yield of around 30 %. As for mvb and lvb coals (Upper Freeport and Pocahontas No. 3), a typical maximum tar yield is around 10 %-20 % (Ko, 1988 and Niksa, 1991). The pyridine extract yields of mvb and lvb coals are also much lower than that of a typical hvb coal, generally amounting to less than 10 %, with a typical hvb coal exhibiting about 30 % yield of pyridine extract (Snape and Bartle, 1991 and Niksa, 1991).

From this study, the idea that all liquid metaplast is a direct precursor of tar (Ko, 1988) has to be reviewed. The mvb and lvb coals in this study produce less tar than a typical hvb coal, but exhibit strong plastic behavior comparable to that of the two hvb coals studied (Pittsburgh No. 8 and Illinois No. 6). Since high-rank coals (mvb and lvb coals) have a smaller fraction of labile bridges than hvb coals, they are less likely to produce the small liquid fragments identifiable as tar precursors, and hence lower tar yields on pyrolysis would be expected (Niksa and Kerstein, 1991). However, mvb and lvb coals are still able to produce larger fragments (possibly a cluster of aromatics) which contribute to their good plastic behavior (Howard, 1991). In light of the present (Figures 4 and 5) results, metaplast is hypothesized to be a combination of smaller fragments ("micrometaplast") and large fragments ("macrometaplast"):

1)

When a plastic coal is heated, it forms both types of metaplast. The good plastic behavior of high-rank coals results from the macrometaplast. High-rank coals do not produce much of the micrometaplast, and their tar yield is generally low. Hvb coals produce both types of metaplast on pyrolysis and therefore have a good tar yield and strong plasticity. Subbituminous and low-rank coals, as well as lignites and peats, have a high fraction of labile bridges for forming the small fragments. However, they are also abundant in oxygen which promotes cross-linking. This results in a small quantity of liquid fragments being produced on pyrolysis and thus low tar yields. They do not exhibit any plastic behavior, and their main product is noncondensable gases (Niksa and Kerstein, 1991, Ko, 1988, and Fong, 1986).

Although all coals studied exhibit better plasticity under 1 atm than under vacuum (Figures 4 and 5), more data obtained at higher pressures are needed before a conclusion on the effects of pressure on coal plasticity can be made.

5. Future Plans

The goal is to perform more runs at different temperature-time histories and pressures. The effect of pressure on the plastic behavior will be investigated in more detail. The presence of gas bubbles in the shearing chamber poses a challenge to the concentrated suspension model of Frankel and Acrivos (Frankel and Acrivos, 1967) which provided one of the inputs for previous modeling of plasticity kinetics (Fong, 1986). To accurately determine the metaplast concentration and the viscosity of a coal during its plastic period, one needs to determine the effect of gas bubbles in the suspension of solid coal and liquid metaplast. Other viscosity models which incorporate gaseous and liquid phases or all three phases (solid, liquid, and gas) will be investigated. Molecular structural data for coals of different ranks will be studied to determine the feasibility of correlating different structural parameters of different coals with their plastic behavior. This will allow one to assess more quantitatively the potential for relating apparent viscosity to coal type. An ultimate benefit of this aspect of the work could be a theory for predicting the plastic behavior of a coal from molecular structural information on the coal.

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