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“Use of Petroleum Coke in Cokemaking and it’s  
Evaluation Through Coke Petrography”

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USE OF PETROLEUM COKE IN COKEMAKING AND  
ITS EVALUATION THROUGH COKE PETROGRAPHY

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Interlake, Inc.

INTRODUCTION

Metallurgical coke used in the blast furnace serves three main functions: (1) to supply energy for the endothermic chemical reactions and to melt iron and slag produced, (2) to provide reducing gases for the reduction of oxides of iron, manganese, silicon, etc., and (3) to provide permeability and support for the furnace burden. To meet the first two requirements, the coke should have as much carbon as possible with a desired chemical reactivity. To meet the last requirement, it should possess a desired particle size distribution to provide an adequate permeability to the reducing gases to optimize heat transfer and chemical reactions taking place between the gases and solids. It should also possess an adequate mechanical strength to support the weight of the materials charged into the blast furnace. Therefore, for an efficient blast furnace operation, it is imperative that the coke must maintain, as much as possible, its original size, shape, and strength from the time it is charged into the blast furnace until it descends to the tuyere level for combustion in the raceway. Thus, in order for the coke to maintain its mechanical strength in the blast furnace, it should withstand physical degradation due to abrasion and compression as well as due to chemical reactions, especially gasification reactions that involve carbon and carbon dioxide. (1) If the furnace charge materials contain an appreciable amount of alkali, the coke should also be able to withstand the alkali attack which manifests itself, acting as a catalyst, by promoting and accelerating the gasification reaction of coke carbon with carbon dioxide. (1)

The recent advances made in coal and coke petrography have enhanced our understanding of the microstructure of coke and allowed us to study the relationship between the coke texture, coke strength and the performance of coke in the blast furnace. Thus, coke petrography coupled with the new test procedures involving

testing of coke under conditions simulating blast furnace operating conditions are establishing themselves as better and more reliable tools to predict the degradation of coke in the blast furnace than the conventional stability test which is carried out at room temperature in the absence of any chemical reaction.

Work presented here involves coke petrography, in general, and how it relates to coke made of a coking coal blend containing petroleum coke, in particular.

PETROLEUM COKE AND ITS USE IN COKEMAKING

Delayed petroleum coke is the end product in the refining of oil. When crude oil is recovered, first it is refined to obtain jet fuel oil, gasoline, heating oil, etc. through fractional distillation process. What is left behind from this process is called distillation residue. This distillation residue is fed to a delay coker either directly or after it is hydro-treated.

Figure 1 shows schematically hydrogenation of the distillation residue in the first step and its subsequent cracking to obtain a gasoline molecule, or other low-boiling point hydrocarbons, indicated as R-R' in the second step. When it becomes uneconomical to continue the extraction process, the residue which is called petroleum pitch, or petroleum tar pitch, which has almost no functional group to be hydrogenated or cracked, is fed to a delay coker. The high pressure in the delay coker rearranges the structure of the petroleum pitch or the distillation residue generating some more low-boiling point hydrocarbons and a final residue which is called delayed petroleum coke.

Petroleum coke has been used in cokemaking in the U.S. and abroad since the 1940's on an on-again-off-again basis. Petroleum coke had been successfully used by Interlake in its cokemaking operations in the 1960's on a trial basis. However, the higher price of petroleum coke prevented Interlake to continue its use. The availability of petroleum coke at prices more attractive than the coking coals led Interlake to resume petroleum coke usage in its coking coal blends starting from April, 1979.

The performance of coke, made of coking coal blends containing petroleum coke, in the blast furnace has been successful and beneficial to Interlake. However, from time to time, difficulties were experienced with coke product. Usually, these difficulties were traced back to the amount or type of petroleum coke used in the coking coal blends. In order to understand the nature of these problems and how Interlake has been able to use petroleum coke successfully in its coking coal blends, an investigation was undertaken to study the basic structure of petroleum coke, and the carbon forms derived from Interlake's coal blends. This investigation also involved

studying the possible degradation behavior of the coke products in a blast furnace by subjecting them to carbon dioxide and air at an elevated temperature.

#### OPTICAL TEXTURE OF COKE - GENERAL

Polished surfaces of metallurgical coke as well as coke made of coal tar or petroleum pitch when examined under a microscope reveal distinguished textures of varying sizes and shapes. Different carbon forms are made from the melt of coal, pitch, or other organic compounds in a phase called liquid crystal.<sup>(2)</sup> Liquid crystal, which is unlike an ordinary liquid, demonstrates some molecular order in certain directions. H. March has found that the size and shape of the optical texture of coke is influenced by the chemical and physical nature of these liquid crystals. In general, there are three main categories of optical textures<sup>(3)</sup> in coke distinguished by shape, and size.

- a. Isotropic - no grains can be seen through an ordinary petrographic (~600X) microscope.
- b. Mosaic - grains can be seen through a petrographic microscope and are either circular or globular.  
  
Fine: < 0.5  $\mu\text{m}$   
Medium: ~1.0  $\mu\text{m}$   
Coarse: ~1.5  $\mu\text{m}$
- c. Flow Type - grains also can be seen through petrographic microscope and are elongated. The size of the elongated coke grains in this case can be more than 200  $\mu\text{m}$  in length. The long and wide flow type grains are called domain.

A complete nomenclature describing optical textures of coke is given in Table I of March's paper.

It is found that coals with a higher aromatic structure will form a coke structure with a larger size optical texture such as flow-type anisotropic or domain. Coal becomes more and more aromatic as the rank moves up. Low rank coal molecules are usually linked to each other by hydrogen bonding; while high rank coal molecules are linked to each other by bonding aromatically. In other words, molecular weight of coal tends to move up as the rank moves up. The presence of heteroatoms or functional groups (such as hydroxyl group, -OH) in the reaction molecules generally makes cross-linkage easier and can be served as nuclei in crystallization process. That is why the size of optical texture in coke decreases

with decreasing coal rank (Figures 2 to 5). As mentioned before, petroleum coke is made of petroleum tar pitch. Petroleum tar pitch is made of crude oil residue by continuous hydrogenation and cracking to remove the last vestiges of low boiling-point hydrocarbons. Therefore, that is the reason why petroleum tar pitch molecules have almost no functional groups at all before feeding into delay coker. The presence of few nuclei during crystallization process only makes the grains bigger. Usually, petroleum coke consists of four types of texture (Figures 6 to 8). Amorphous phase in petroleum coke usually dissolves into other phases during cokemaking, but the other types of texture do not change too much.

For the purpose of simplicity and clarity, three main coke textures and petroleum coke texture present in Interlake coke and the sources of coal contributing to these textures are dealt with in this article. This is summarized in Table 1.

#### COKE STRENGTH vs COKE TEXTURE

The strength of coke depends upon its porosity, nature of its pore-wall structure, and pore size distribution. Coke strength decreases with increasing volume fraction of porosity, a more irregular pore structure, or internal cracking.

For a coke of given porosity and structure, its strength depends upon the composition of the solid pore-wall material. The optical microscope can reveal the microstructure and phases which can be determined quantitatively. The calculation of the theoretical stability, based on the mechanics of coke strength from initial amount of different entities in coal, materials, is almost impossible. However, R. Gray of U.S. Steel developed a technique to estimate the coke strength through<sup>(4)</sup> statistical method based on coal structure. Additional information can be deduced from coke petrography or from material science. For example, the isotropic phase is relatively weak and brittle. The anisotropic phase with large optical texture is relatively easy for crack propagation to occur parallel to the basal planes of the constituent lamellar molecules in macrocrystals. The nature of the petroleum coke makes the structure of coke made from it weak (Figures 9 & 10); for example, the stability of coke made from 100% petroleum coke was found to be only 32 ASTM stability. Petroleum coke in coke usually not only does not have a good binding to its surrounding, but also does not have a good binding to itself. A comparative study of the microstrength of coke and their optical texture<sup>(5)</sup> has been made by Ragan and March. They suggested that coke strength increases due to the presence of mosaic carbon forms as they tend to resist the propagation of cracks which may originate from domain anisotropic area. The same reason holds when a carbon electrode used in the aluminum industry was made by

adding tar pitch to needle petroleum coke. The function of tar pitch is to glue these needle petroleum coke grains together and prevent cracking along their basal plane direction. It is also a well-known fact that "flow-type gives the strength and mosaic supplies the binding." Flow-type carbon forms are usually just like the reinforcing bar in concrete and give the strength; mosaic carbon forms serve like cement and supply the binding. However, when the anisotropy of carbon forms reaches domain structure, its reinforcing effect becomes less significant, and thus their contribution to coke strength decreases. Coincident to the above, R. Gray<sup>(4)</sup> also found that coke made by an individual vitrinoid (V) group reached a maximum strength around V17, and then dropped off sharply. High reflectance low-volatile coal (V18 or higher) is one of the major sources to produce domain texture in coke. In addition, the flow direction of flow-type carbon forms is very often along the pore-wall direction, thus reinforcing the coke structure. This is analogous to the structure of a hot-rolled railroad wheel where the tensile strength is the highest in tangential direction due to its grain orientation as shown in Figure 11. In summary, the relative strength of carbon forms can be compared in relation to one another as shown in Table III.

#### COKE REACTIVITY OR CARBON DIOXIDE ATTACK vs COKE TEXTURE

It is important to discuss CO<sub>2</sub> attack by taking into account all of the following factors: (a) rate of gasification, (b) the surface topography induced by gasification, and (c) coke structure.

The blast furnace operator usually requires a controllable and relatively less-reactive coke. Excessive gasification in the upper regions of the blast furnace prior to entering the raceway creates "Solution-Loss" which is a kind of waste. In addition, enlargement of microcracks, fissures, or certain areas by highly selective gasification mechanisms results in a tremendous decrease in coke strength. It is now recognized that anisotropic carbon is less reactive to carbon dioxide than isotropic carbon. Two speculated explanations are: (a) a smaller total surface area of the carbon available for reaction, and (b) less intrinsic reactivity of molecules constituting the anisotropic carbon than those of the isotropic carbon. Reactivity reaches a minimum in elongated anisotropic area with a mean maximum reflectance of about 1.40%.<sup>(6)</sup> Then reactivity increases again as the degree of anisotropy increases. For example, domain structure is relatively more reactive. The low-volatile coal has a mean maximum reflectance of 1.90%; of course, it could not withstand CO<sub>2</sub> attack too well. Carbon forms made from coals usually have tight structures (Figures 2 to 5). The carbon forms made from tar pitch, tar, and ordinary crude residue, are generally somewhat loosely packed - but still denser than those from petroleum

coke. As a result, the reactivity of the coke in the petroleum coke region is high due to its texture. The reason for the loose structure in petroleum coke region is still unknown.

In addition, an optimum amount of fluid coal usage in a coking coal blend can minimize reaction surface area per unit weight, because only fluid coal can fill the porosity between the inerts, such as petroleum coke, making them somewhat impermeable to the CO<sub>2</sub> attack. Inerts or low-volatile coals can increase the thickness of the pore-wall, thus increasing the density of the coke produced. However, it is the surface tension of fluid coal during the cokemaking process which seals off the porosity. These pores are the primary channels for CO<sub>2</sub> and alkali permeation into the coke. Less cracks and less strain can be observed under a microscope when enough fluid coal is added into the coal blend. At Interlake, the coal blend used usually contains a high percentage of inerts. Fluid coal then becomes a key factor in the determination of the coke quality in Interlake's blast furnace operation.

It is observed that when there is a prolonged CO<sub>2</sub> attack in a region of medium or coarse mosaic carbon forms, it produces only a general corrosion or a pit corrosion at the worst. Thus, CO<sub>2</sub> needs longer times in order to weaken a mosaic coke structure (Figure 12). However, corrosion along petroleum coke particles or deep penetration into the petroleum coke grain boundaries can be more severe, as can be attested in Figures 12, 13, and 14. High percentages of coke fines in the size range of a few micron were seen in the raceway directly through the fiber-scope, when more than 14% petroleum coke was used in the coking coal blend. These fine particles are probably the cause of the loss of furnace permeability and the cause of an excessive heat generated in tuyere zone because of the high reactivity of coke in the micron size range.

In order to understand the coke gasification process better, a sample of Interlake's furnace coke, in the size of roughly 1 cm in diameter, was reacted with CO<sub>2</sub> for four hours in our reactivity tester. The use of 1 cm diameter coke for the reactivity test, instead of coke in powder form, is to emphasize the reaction of coke and CO<sub>2</sub> under conditions similar to blast furnace environment. This way, coke structure, not the coke size will be a dominant factor to control the speed of CO<sub>2</sub> attack and the reaction of CO<sub>2</sub> attack.

"Relative Micro Reactivity" (RMR) is defined by the ratio of weight loss of an individual type of carbon form under CO<sub>2</sub> attack to the average value of the whole specimen. For the textures with RMR greater than unity, they are relatively reactive. W-K Ly<sup>(7)</sup> found a similar result in his recent work. The isotropic, granular flow and domain emanating from both low volatile coal or petroleum coke in

Interlake's furnace coke are very reactive; while the medium and coarse mosaic are relatively inert. The experimental conditions and results are given in Table IV.

Interlake's coke is different from many others in that the blend contains petroleum coke. In trying to assess Interlake's coke quality, we have utilized reactivity tests although a reactivity test cannot predict the degree of alkali attack, it can only give us a relative rough measure of the soundness of the coke structure. A high reactivity and a low coke strength after reactivity test may mean that the coke is more susceptible to deterioration in the blast furnace. The variables that affect coke reactivity are listed in the following:

(a) The Freshness Of Raw Coals

More oxidation in coals means more irregularity in coke structure, and thus higher reactivity.

(b) Amount Of Fluid Coal

Enough fluid coal means less reaction surface area and less reactivity.

(c) The Type Of Fluid Coal

Mosaic made of V10 type fluid coal is both stronger and more resistant to CO<sub>2</sub> than that made of V9 type, which, in turn, is better than that made of V8 type.

(d) The Amount Of Petroleum Coke

More petroleum coke means more irregular coke structure and thus higher reactivity.

(e) The Presence Of Illinois Coke

The isotropic phase generated from Illinois coal means higher reactivity.

ALKALI ATTACK vs COKE TEXTURE

The presence of alkali in the blast furnace can have two-fold deleterious effect. It can act as a catalyst speeding up the solution-loss reaction and can cause disintegration of the coke, even in an inert atmosphere. (7,8,9) It was observed that the extent of reaction of alkali with coke increased with the increasing degree of anisotropy. Besides, alkali narrows the reactivity gap between extreme cases. In other words, coke under the influence of alkali tends to (a) speed up all the gasification rate of all carbon forms (b) the flow-type anisotropic or domain reacts preferentially to create extensive fissuring, (c) the deterioration rate of medium/coarse mosaics will speed up dramatically; but, they are still slower than other carbon forms. Isotropic texture is very inert to alkali attack. The effect of alkali attack can be summarized in

Table VI. (3,7)

COKE REACTIVITY DURING BURNING vs COKE TEXTURE

The purpose of furnace coke is to be burned in the blast furnace. Another point count was made on Interlake's furnace coke, before and after burning it in the air. Chunks of coke, in the order of 1 cm diameter, were placed in a 1000°C tube furnace, and then was blown in air with an electric fan for almost 20 minutes. The left-over red-hot coke was quickly air-quenched. After washing with de-ionized water to remove ash, these coke pieces were dried and mounted on epoxy. A polished coke surface provided the information in Table VII.

Again, various carbon forms were oxidized at different rates. The mosaic carbon form still had the lowest reaction rate and tended to remain intact. The method of corrosion in mosaic carbon form was almost the same as the previous case. Some of the phases from petroleum coke were easily blown away, into even finer particles by the electric fan. (Figure 15)

CONCLUSIONS

The use of petroleum coke in Interlake's coking coal blends and the additional information acquired from laboratory scale investigations has determined that:

- (1) The coke must have reasonable resistance to carbon dioxide attack. The carbon forms present in the coke due to the use of petroleum coke were found to be extremely vulnerable to carbon dioxide attack. The carbon dioxide attack on coke with isotropic texture derived from the use of an Illinois coal, which is a high volatile, low fluidity bituminous coal was found also to be as severe as the coke made using a percentage of Petroleum coke in the coal charge.
- (2) The coke must have resistance to alkali vapor attack. The coke absorbs alkali vapors from the gaseous phase to form intercalation compounds by introducing new compounds between the existing molecular structure in the pore-walls thus weakening the coke strength. The more irregular and the more anisotropic the coke texture, the more severe is the deterioration of the coke strength due to the alkali attack. The use of petroleum coke reduces the resistance to alkali vapor attack.
- (3) Carbon forms in coke derived from petroleum coke need enough fluid coal to form an anisotropic mosaic structure around the petroleum coke to protect them from carbon dioxide and alkali attack.
- (4) The amount of fluid coal required would be different from blast furnace to blast furnace and the iron production rate at that time.
- (5) The petroleum coke usage should be set,

at the most, 10% in the coal blend.

- (6) Petroleum coke with higher volatile matter has more flexibility for cokemaking and thus reduces the requirement of fluid coal. This is in agreement with the findings of Forrest & Marsh. (10)

#### ACKNOWLEDGEMENT

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TABLE I. TEXTURE AND GRAIN STRUCTURE OF INTERLAKE COKE

<u>TEXTURE</u>		<u>GRAIN STRUCTURE</u>	<u>MAJOR SOURCES</u>
Isotropic		Plain, No Grains Can Be Seen	Illinois Coal
Mosaic	Medium Course	~ 1.0 $\mu$ m Dia. ~ 1.5 $\mu$ m Dia.	Fluid Coal
Flow-Type		Elongated Flow, Domain	Low-Volatile Coal
Petroleum Coke		Giant Mosaic, Needle, Domain	Petroleum Coke

TABLE II. TYPICAL COAL BLEND

<u>Type Of Coal</u>	<u>Example</u>	<u>% In Blend</u>
High Volatile Coal	Illinois	20 $\rightarrow$ 30%
High Volatile Fluid Coal	Scotia	45%
Low Volatile Coal	Olga	25%
Petroleum Coke	Petroleum Coke	0 $\rightarrow$ 10%

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<u>Name</u>	<u>H<sub>2</sub>O</u>	<u>Proximate, %</u>			<u>S</u>	<u>M.M.R., %</u>	<u>Fluidity, d.d.p.m.</u>	<u>Inert, %</u>
		<u>V.M.</u>	<u>F.C.</u>	<u>Ash</u>				
Illinois	10.0	37.0	53.0	10.0	1.10	0.66	30	14.4
Scotia	6.5	35.5	57.5	7.0	0.90	0.93	30,000	22.0
Olga	6.5	17.0	77.0	6.0	0.75	1.80	60	33.0
Petroleum Coke	8.0	17.5	82.0	0.5	5.0	-	0.5	-

TABLE III. STRENGTH OF VARIOUS CARBON FORMS IN COKE (4)

<u>Isotropic</u>	<u>Medium &amp; Coarse Mosaics</u>	<u>Flow-Type Anisotropic Excluding Domain</u>	<u>Petroleum Coke</u>
Weak	Medium	Strong	Weak

TABLE IV. ANALYSIS OF OPTICAL TEXTURE OF A TYPICAL INTERLAKE COKE PRODUCED ON MARCH 28, 1983 AND ITS RATE OF GASIFICATION WITH CARBON DIOXIDE GAS

1100°C : 4 Hours  
CO<sub>2</sub> Flow Rate: 5 l/min.

(1) Assuming Ash = 8.0% In Carbon Forms - (2) 38% Burning-Off

Texture	Analysis Of Coke Texture, %					Weight Of Coke Texture, Gram				
	Iso.	Mos.	Flow	Pet.	Inerts	Iso.	Mos.	Flow	Pet.	Inerts
(a) Original (Before Burn-Off)	14.4	44.4	19.3	13.5	8.5	13.2	40.8	17.8	12.4	7.8
(b) After Burn-Off	7.5	52.2	20.1	9.8	10.3	4.1	28.2	10.9	5.3	5.6
(c) Burn-Off Rate	68.9	30.9	38.8	57.3	28.2	9.1	12.6	6.9	7.1	2.2
(d) Relative Micro Reactivity	1.8	0.8	1.0	1.5	0.7					

Burning-off rate is defined by  $A = \left(\frac{\Delta W}{W}\right) \%$ , where  $\Delta W = (a) - (b)$ .

Relative Micro Reactivity is defined by  $\frac{A}{\% \text{ of B.O.}}$

TABLE V. RESISTANCE OF CARBON FORMS UNDER CO<sub>2</sub> ATTACK IN INTERLAKE'S FURNACE COKE (6)

Isotropic	Anisotropic	Flow-Type	Petroleum Coke
Weak	Strong	Weak	Weak

TABLE VI. ALKALI RESISTANCE OF VARIOUS CARBON FORMS IN INTERLAKE'S FURNACE COKE

Isotropic	Anisotropic	Flow-Type	Petroleum Coke
Strong	Medium	Weak	Weakest

TABLE VII. ANALYSIS OF OPTICAL TEXTURE OF A TYPICAL INTERLAKE COKE PRODUCED ON MARCH 28, 1983 AND ITS REACTION RATE WITH AIR

(1) Assuming Ash = 8.0% in Carbon Forms  
(2) 48.6% Burning-Off

Texture	Analysis Of Coke Texture, %					Weight Of Coke Texture, Gram				
	Iso.	Mos.	Flow	Pet.	Inerts	Iso.	Mos.	Flow	Pet.	Inerts
(a) Original (Before Burn-Off)	14.4	44.4	19.3	13.5	8.5	13.2	40.8	17.8	12.4	7.8
(b) After Burn- Off	9.2	46.8	21.3	11.5	11.3	4.0	20.3	9.2	5.0	4.9
(c) Burn-Off Rate	69.7	50.2	48.3	59.7	37.2	9.2	20.5	8.6	7.4	2.9
(d) Relative Micro Reactivity	1.4	1.0	1.0	1.2	0.8					

Burning-off rate is defined by  $A = \left(\frac{\Delta W}{W}\right) \%$ , where  $\Delta W = (a) - (b)$

Relative Micro Reactivity is defined by  $\frac{A}{\% \text{ of B.O.}}$



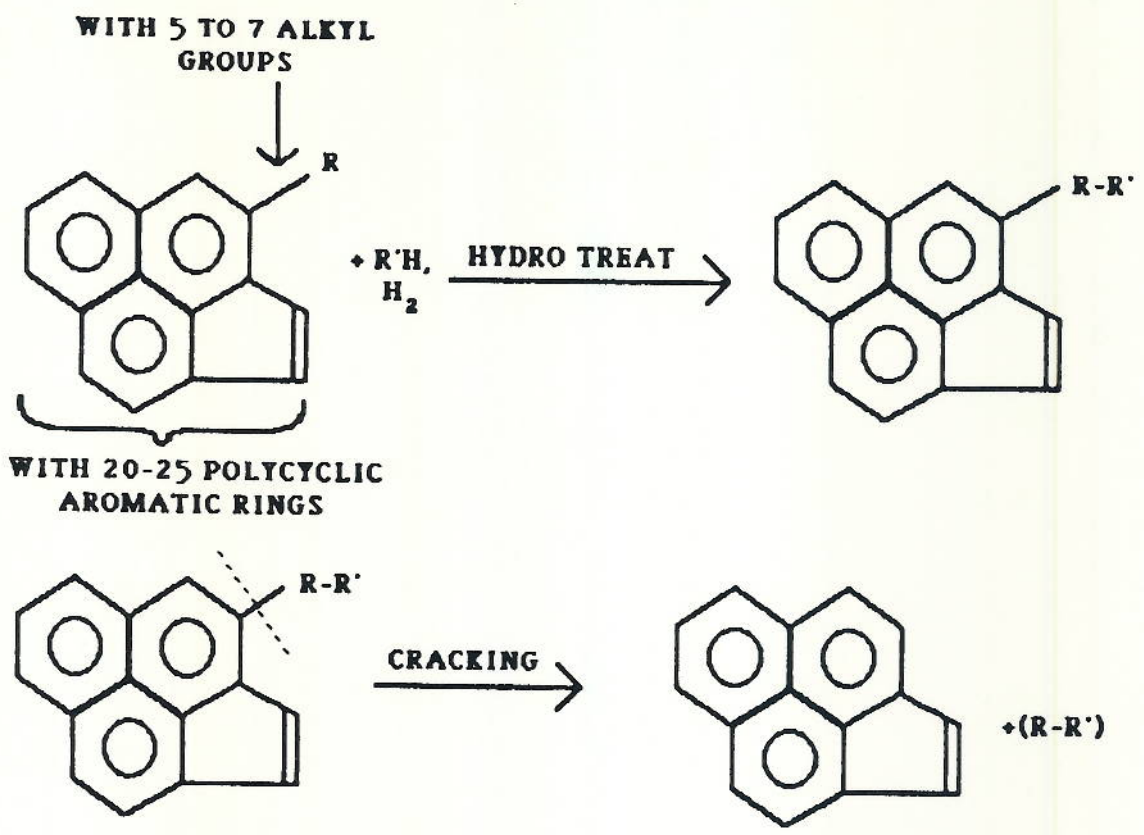


FIGURE 1. EXAMPLE OF HYDROGENATION AND CRACKING OF CRUDE OIL RESIDUE

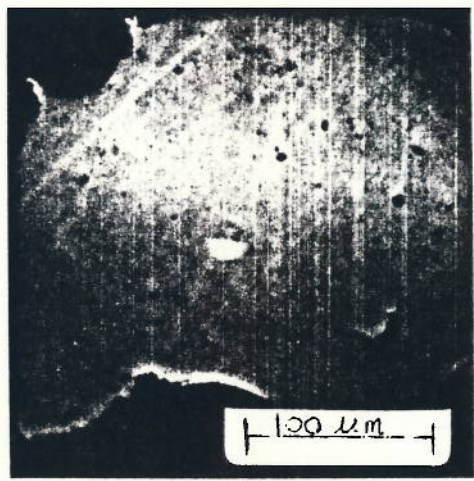


FIGURE 2. ISOTROPIC TEXTURE OF COKE MADE OF ILLINOIS COAL  
MEAN MAXIMUM REFLECTANCE: .65%

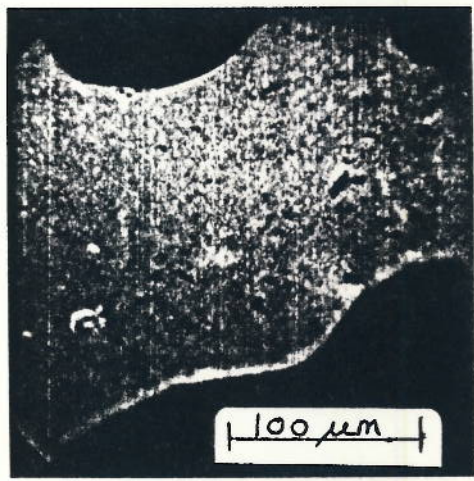


FIGURE 3. MEDIUM SIZE MOSAIC TEXTURE OF COKE MADE OF MCCOY-ELKHORN COAL  
MEAN MAXIMUM REFLECTANCE: 0.99%

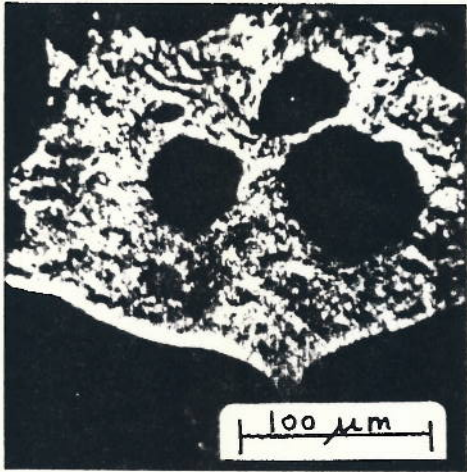


FIGURE 4. COARSE SIZE MOSAIC AND  
ELONGATED ANISOTROPIC TEXTURE  
OF COKE MADE OF BISHOP COAL  
MEAN MAXIMUM REFLECTANCE: 1.40%

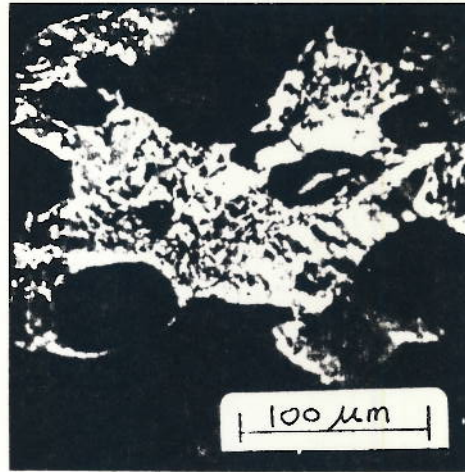


FIGURE 5. FLOW TYPE AND DOMAIN TEXTURE  
OF COKE MADE OF POCAHONTAS  
COAL.  
MEAN MAXIMUM REFLECTANCE: 1.90%



FIGURE 6. PETROLEUM COKE  
PRECURSOR OF NEEDLE STRUCTURE

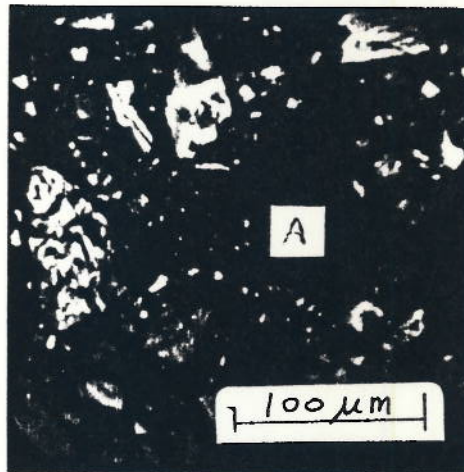


FIGURE 7. PETROLEUM COKE  
POSITION A = AMORPHOUS PHASE

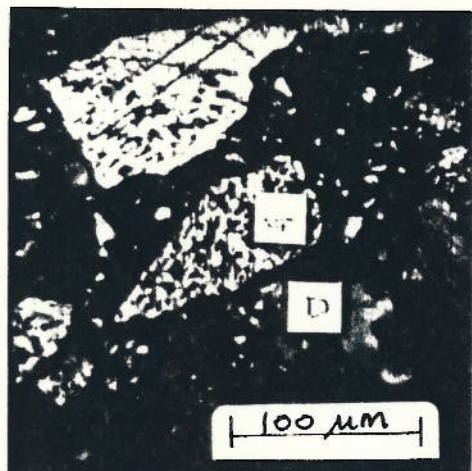


FIGURE 8. PETROLEUM COKE  
 POSITION G = PRECURSOR OF  
 GIANT MOSAIC  
 POSITION D = PRECURSOR OF  
 DOMAIN

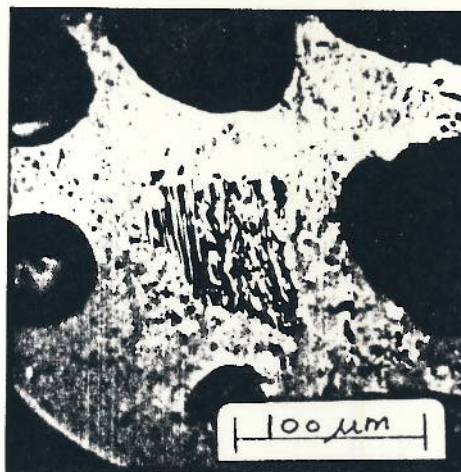


FIGURE 9. PETROKLEUM COKE  
 INSIDE COKE

Note: (1) Loose Petroleum  
 Coke Structure  
 (2) Built-in Cracks  
 Inside Petroleum  
 Coke  
 (3) Cracks In Coke  
 Due To The Presence Of  
 Petroleum Coke



FIGURE 10. PETROLEUM COKE  
 INSIDE COKE



FIGURE 12. CO<sub>2</sub> ONLY CAUSES  
 GENERAL CORROSION OR PIT  
 CORROSION ON MOSAIC TEXTURE.  
 HOWEVER, CO<sub>2</sub> CORRODES  
 PETROLEUM COKE ALONG THE  
 BOUNDARY (INITIAL STAGE)

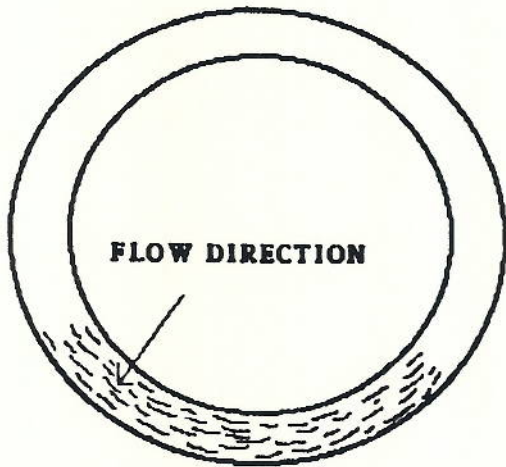
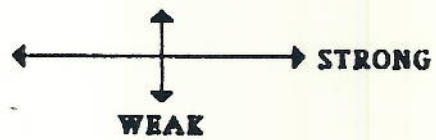
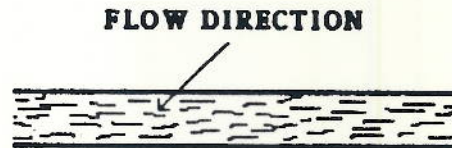


FIGURE 11. (a) Grain Structure Of A Railroad Wheel



(b) Tensile Strength vs Grain Flow Direction

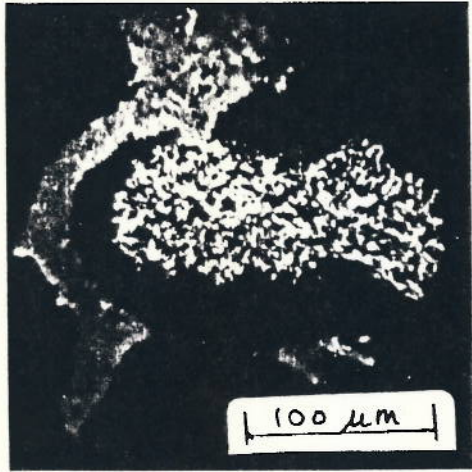


FIGURE 13.  $\text{CO}_2$  CORROSION ALONG THE PETROLEUM COKE BOUNDARY IN ITS FINAL STAGE



FIGURE 14. NOT ONLY PETROLEUM COKE CAN SEPARATE FROM COKE EASILY, BUT ALSO IT CAN DISINTEGRATE INTO EVEN FINER PARTICLES ITSELF AS A RESULT OF  $\text{CO}_2$  ATTACKING ON ITS LOOSE STRUCTURE

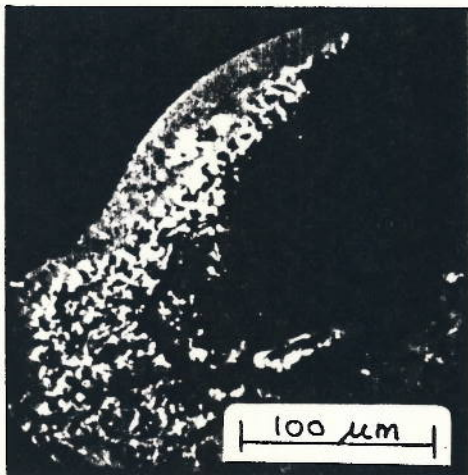


FIGURE 15. DURING BURNING, PETROLEUM COKE CAN ALSO DISINTEGRATE INTO EVEN FINER PARTICLES.

Slide No. 1 to 3: Interlake's Coke Oven

Slide No. 4: Petrographic Microscope - Zeiss Photometer 03 Model

Slide No. 5: Function of Coke in Blast Furnace

Slide No. 6: Deterioration of Coke

Slide No. 7: Interlake's Present Situation

Slide No. 8: New Approach

Slide No. 9: Make of Petroleum Coke

Slide No. 10 to 12: Microstructure of Raw Petroleum Coke, Four Categories:  
Coarse Mosaic, Needle, Domain & Amorphous.  
Except Amorphous Phase, others will not change too much  
after cokemaking.

Slide No. 13: Typical Proximate of Pet Coke

	<u>Supplier I</u>	<u>Supplier II</u>	<u>Supplier III</u>	<u>Supplier IV</u>
V.M.	17-26%	11-14%	~ 13%	10-13%
Ash	0.1-0.4%	0.1-1.5%	~ 0.3%	~ 0.3%
S	3.0-6.0%	3.0-6.0%	3.0-5.0%	3.0-5.0%
F.C.	Balance	Balance	Balance	Balance

Slide No. 14: Typical Petroleum Coke's MMR, Fluidity and V.M.

<u>Sample</u>	<u>Fluidity, d.d.p.m.</u>	<u>M.M.R. %</u>	<u>V.M. %</u>
A	0.4	3.180	-
B	1.0	3.150	15.97
C	1.7	2.866	15.92
D	30,000 (371°C-486°C)	1.862	25.57
E	30.000 (300°C-500°C)	0.632	50.35

Slide No. 15: Coke Optical Textures vs. Their Characters

<u>Optical Texture</u>	<u>Mechanical Damage</u>	<u>CO<sub>2</sub> Attack</u>	<u>Alkali Attack</u>
Isotropic	Weak	Weak	Strong
Anisotropic	Medium	Strong	Medium
Flow Type	Strong	Medium	Weak
Petroleum Coke	Weak	Weak	Weak

Slide No. 16: Coke made by Crude Oil Residue

Slide No. 17: Coke made by Tar

Slide No. 18: Microstructure of Coke made by Illinois Coal - Instropic Phase

Slide No. 19: Microstructure of Coke made by McCoy-Elkhorn - Anisotropic Phase

Slide No. 20: Microstructure of Coke made by Bishop Coal

Slide No. 21: Microstructure of Coke made by Pocahontas Coal (MMR = 1.90%)

Slide No. 22 - 23: Mechanical Weakness of Petroleum Coke

Slide No. 24: Grain Flow Direction of Flow-Type Carbon Forms in Coke

Slide No. 25: Grain Structure of a Railroad Wheel

Slide No. 26: Tensile Strength vs. Grain Flow Direction

Slide No. 27: Grain Flow Direction of Pet-Coke in Coke

Slide No. 28-29: Anisotropic Carbon Forms after CO<sub>2</sub> Attack. Initial stage of CO<sub>2</sub> attack along Pet-coke boundary.

Slide No. 30: Final Stage of CO<sub>2</sub> Attack Along Pet-Coke Boundary.

Slide No. 31-32: Petroleum Coke (Inside coke) can Split into even Finer Particles upon CO<sub>2</sub> Attack

Slide No. 33: Petroleum Coke (inside Coke) also can Split into Even Finer Particles on Burning

Slide No. 34: Conclusion

- (1) Limit the amount of Petroleum Coke under 10%
- (2) Integrity of coke depends upon fluid coal -  
Anisotropic carbon forms protect the Petroleum Coke.
- (3) This approach works the best during deep recession.