The effects of inert matters and low volatile coal addition on the plasticity of high volatile Zonguldak coals

by V. Arslan* and M. Kemal*

Transaction Paper

Synopsis

In this study, effects of the inert constituents, such as ash, and the effect of blending coals with differing rank and composition on the plasticity of coal blends were investigated. The reference coal originated from the Zonguldak region, in the north-west part of Turkey. Firstly, the effect of coal ash on the plasticity of Zonguldak coal was determined. Secondly, the relationship between the plastic properties of the individual coals and those of the blended coals were identified. Some important relations were found, related to the characteristics of the individual coals. Ultimately, the manner in which the plasticity of Zonguldak coal was affected by blending with low volatile coals was investigated.

Keywords: coal blending, coal plasticity, coke, fluidity, rank.

Introduction

Zonguldak coal is the only source of coking coal in Turkey. However, due to its general properties, it is not suitable for coke making, on its own, in modern large blast furnaces. Furthermore, due to insufficient production capacity, its use in coke production has not been at the desired level.

The best coals for coke making have 24–26% dry ash free (daf) volatile matter, but reserves of such suitable coals are insufficient. In the classical way of coke producing, blending with some other coals is common practice, and the usable coal range broadens to 18–38% volatile matter (daf). Such blending also facilitates the usage of coals which would otherwise not be used individually in metallurgical coke making, because of some undesired chemical and coking properties. The most important thing in the coal, blends for metallurgical coke production is that the coals must complement each other. The blend should be characterized by volatile matter between 24–26% (daf), a mean vitrinite reflectance of *ca.* 1.2% and maximum fluidity between 200–1000 dial divisions per minute (ddpm). Also, the fluidity of the coals must affect the fluidity of the blends in a positive manner and widen the plastic range. Furthermore, the duration period in high fluidity levels has to be long[1–4].

In coal blending, the effects of the blend components on the plasticity and on the coke strength of the final blend are the main parameters. Coals that can be blended in theory, may not give the estimated value in practice. Much research has shown that some individual characteristics are balanced by their ratios. However, in the case of the plastic properties of individual coals, there is no direct relation to their proportions in the blend[4–6].

Various investigations have been carried out on the relationship between the plasticity of individual coals and that of the final blend. Some of these are summarized below.

According to Kosina[7], to blend low-rank non-caking coal with a medium-rank strongly caking coal displays distinct deviations from additivity in blends regarding the values of fluidity.

Lin[8] shows that, when the fluidity of coals is low, the interaction of coal particles is limited only to the contact surface. The addition of high fluidity coal can improve this interaction between the coal particles. When such high fluidity coals are added to a blend, the strength of the resulting coke is dominated by the fluidity, when it is lower than 200 ddpm. However, if the fluidity exceeds 200 ddpm, the resulting coke strength is dominated by the rank of the coal.

The molecular organization in the coke is also dependent on the rank of the parent coals, provided the fluidity of the blend of coals is

* *Dokuz Eylul University, Engineering Faculty, Mining Engineering Department, Bornova, Izmir, Turkey.*

© *The South African Institute of Mining and Metallurgy, 2006.* *SA ISSN 0038–223X/3.00 + 0.00. Paper received Oct. 2004; revised paper received Jan. 2005.*

sufficiently high. The molecular organization in the coke resulting from a blend of coals is higher than in the cokes resulting from each individual coal. When the blend contains a good coking coal with high plastic properties, and low or high rank coals, the coke characteristic is generally better in practice than if it were estimated by the additivity rule[3,6,9–11].

Investigations into the relations between the characteristics of individual coals and those of the blend coke specifications have been given by many formulas. Such correlations are generally based on the plastic properties of coal, their petrographic composition and vitrinite reflectance. All researchers have established very precise relations, but the common result from these studies is that they cannot be generalized for all coals. For that reason, the correlations found through specific research of identified coals can be used for those same coals in the plant where the research was conducted[1, 2, 4–6].

Characterization of Zonguldak coals

In this study, changes to the plasticity of Zonguldak coals by addition of inerts and the effect of blended coal characteristics and ratios on plasticity were investigated using the Gieseler plastometer.

For this purpose, first the properties of Zonguldak coal were reviewed and results are given in Table I. With these specifications, Zonguldak coal is classified as high-volatile bituminous A coal according to the ASTM classification system[2,12].

Materials and methods

Samples used for tests

In this study three different coals were used. The main coal was obtained from the Zonguldak Coal washing plant (Zonguldak coal (Z)). The other two coals originated from the Eregli Iron and Steel Company, and they were used as additives for blending tests. Ash, volatile matter and vitrinite reflections were determined on the three coals and are reported in Table II and Figure 1-a, 1-b and 1-c. Unlike the Zonguldak coal, the other coals are classified as low to medium volatile bituminous coals (LV-1 and LV-2)[1]. According the vitrinite reflectance histogram as seen in Figure 1-b and 1-c, LV-1 and LV-2 coals are blended coals. From vitrinite histograms, it can be said that LV-2 coal is blend of a minimum of 2 coals; LV-1 coal is a blend of a minimum of 4 or 5 coals. Some coals those are in the blend of LV-1 have very high mean vitrinite reflectance (about 1.7%). This explains why LV-1 has very bad coking properties.

Tests and analysis

Firstly, the effect of the coal ash (conveniently used as an expression of the impurities present in coal) on the plasticity properties of the coals was examined. For this purpose, samples with different ash contents were prepared by beneficiating at different densities using zinc chloride. Gieseler plastometer tests were performed on the samples having 6%, 8%, 10%, 11%, 12% and 14% ash content. Thereafter, changes in the coking characteristics of the Zonguldak coal were examined by adding different amounts of the other two coals.

Results

The effect of ash on plasticity

Plasticity characteristics of the Zonguldak coal at different ash contents are reported in Table III.

The test results show that the main effect of ash is on the fluidity. The maximum fluidity decreases from 1335 ddpm at 6% ash to 590 ddpm at 14% ash, with no significant change in the plastic range (about 66°C) nor in the initial softening and resolidification temperatures.

The mathematical model was fitted to investigate the correlation between the coal ash and maximum fluidity. The correlation is expressed as follows:

Max. Fluididty (ddpm): $2499–244^{*}(\text{ash }\%) + 7.77^{*}(\text{ash }\%)^{2}$ with a correlation coefficient of 0.986.

In literature it is stated that the viscosity of a fluid in pulp increases slowly when the solid ratio increases to a certain value, thereafter viscosity increases rapidly. This may explain the rapid decrease in fluidity from 1335 ddpm to 980 ddpm with increasing ash from 6% to 8%. As a result, the changes in the fluidity are slower for the lower ash and higher ash, resulting in a higher decrease of the fluidity[13, 14].

Table I
General characteristics of Zonguldak coal[2, 12]

Ash (db) %	Vol. mat. (daf)%	Total S (db) %	Dilatation %	FSI	Mean random reflectance	Max. fluidity	
						ddpm	°C
12 ±2	32 ±2	Max. 0.8	+60 – +90	7–9	0.95–1.1	600–2000	≅460

Maceral analysis (including minerals, % by volume)				
Vitrinite	Liptinite	Semifusinite	Inertinite	Minerals
68	5	6	15	6

Distribution vitrinite reflectance V-classes					
V7	V8	V9	V10	V11	V12
1.0	10.1	29.2	39.5	18.9	1.3

Table II

Ash, volatile matter and mean vitrinite reflectance of coals from Eregli Iron and Steel Company

	Z	LV-1	LV-2
Ash (db) %	11.2	8.6	8.0
Volatile matter (daf) %	29.9	18.9	21.4
Mean vitrinite reflectance (Ro) %	1.11	1.26	1.21

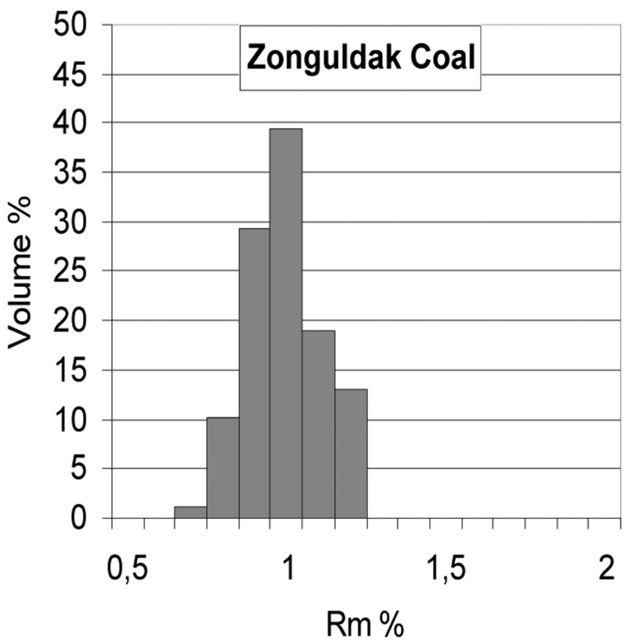

Figure 1a—Vitrinite type distribution of Zonguldak coal

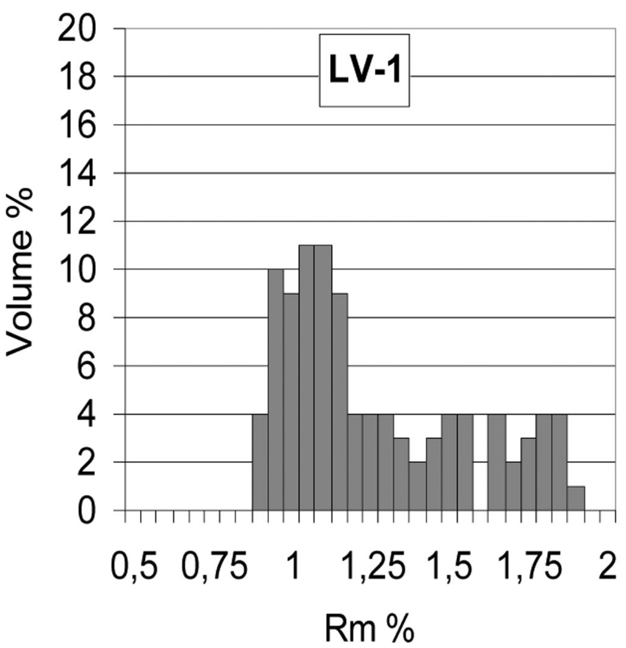

Figure 1b—Vitrinite type distribution of LV-1

Investigation of the effects of components in coal blends

Table IV reports the plastic properties of the coal samples used in blending. From the results, it can be seen that Z and LV-2 coals reported values required for coking coals. On its own, LV-1 is not suitable for coking.

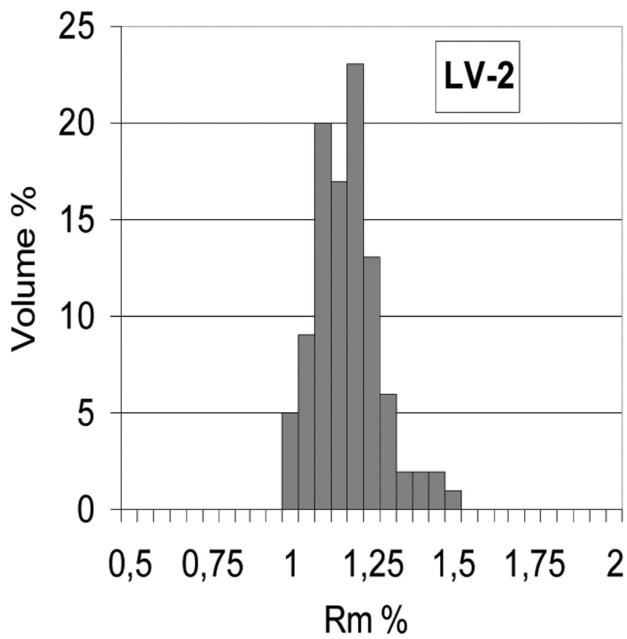

Figure 1c—Vitrinite type distribution of LV-2

Table III

The effect of ash ratio on the plasticity of Zonguldak coal

Ash%	Initial softening °C	Maximum fluidity		Resolidification	Plastic range
		ddpm	°C	°C	°C
6	417	1335	453	483	66
8	414	980	453	486	72
10	414	885	447	477	63
11	414	720	450	480	66
12	411	723	447	477	66
14	414	590	450	480	66

Table IV

Plastometer test results for the coal samples used in blending

Coal	Initial softening °C	Maximum fluidity		Resolidification	Plastic range
		ddpm	°C	°C	°C
Z	408	780	440	466	58
LV-1	436	68	464	486	50
LV-2	428	1290	465	497	69

Table V

Plastometer test results of Z and LV-1 coals blends

Coal ratio in blends		Initial softening	Maximum fluidity		Solidification
Z%	LV-1%	°C	ddpm	°C	°C
100	0	408	780	440	466
80	20	410	500	446	473
60	40	424	285	454	482
20	80	426	108	459	482
0	100	436	68	464	486

Table VI

Plastometer test results of Z and LV-2 coals blends

Coal ratio in blends		Initial softening	Maximum fluidity		Solidification
Z%	LV-2%	°C	ddpm	°C	°C
100	0	408	780	440	471
80	20	408	560	449	482
60	40	417	700	4654	495
40	60	417	735	465	499
20	80	416	955	467	499
10	90	418	1030	461	492
0	100	428	1290	465	497

As seen from the table, LV-1 has very narrow and LV-2 has the widest plastic range. In terms of plasticity, Z coal, the main component in blending is in the range of suitable coals for coke making.

As previously mentioned, although Z coal may be classified as good coking coal on the basis of its plastic properties, the resulting coke strength obtained from such a type of coal will not be at the required level for blast furnaces[3–5]. In order to produce strong coke, the high volatile Z coal must be blended with low volatile coals. Thus, the Z coal was taken as a main blend component and blended at different ratios' and plastometer tests on these blends were done.

Z and LV-1 coal blends

Plastometer tests were performed on the blends obtained by adding LV-1 coal (high initial softening temperature and very low fluidity, 68 ddpm) to Z coal; plastometer tests were done. Results are given in Table V and Figure 2.

When coals with different initial softening and resolidification temperatures are blended, the plasticity range of the blends widened according to the individual coals. However, in the case of the current blends, when the amount of Z coal declined, the fluidity of the blend quickly decreased. Figure 1 shows the initial softening temperature of blends develops slowly, and the plastic range remains similar until LV-1 coal is predominant, when the range narrows.

Z and LV-2 coal blends

Results of plastometer tests of blends of Z and LV-2 coals are given in Table VI and Figure 3. When LV-2 coal having higher initial softening and resolidification temperatures than Z coal were blended together, a rapid fall in maximum fluidity of blend was observed. However the plasticity range of blend was widened. It can be related to the vitrinite histograms given in Figure 1-a and 1-c. If they are examined, it is seen that those two coals are not similar enough to show very good coking properties. As known, in coal blend for coke making, vitrinite histograms must have only one maximum point (as seen in Z coals' individual vitrinite histogram) to develop good coking mechanisms.

From Figure 3, it is seen that plasticity regions of Z and LV-2 coals overlap. Since the difference between maximum fluidity temperatures of these coals was 25°C, the maximum fluidity of the blends becomes smaller than the arithmetic mean value.

Plastometer test results of Z and coke blends

In addition to the suite of tests reported above, in order to observe the effect of carbon as an inert additive, coke, as the inert substance, was added to Z coal. The results are illustrated in Figure 4. It was observed that an increase in coke in the blend resulted in a decrease in fluidity. However, plasticity range decreased with the increasing coke component in the blend, perhaps an expected outcome.

Thus, it is well understood that, when two different coals with different plasticity ranges are blended, the beginning of softening is governed by the coal blend component showing a low initial softening temperature, whereas the coal blend component with high initial softening temperature showed an inert behaviour. At higher temperature this situation is reversed.

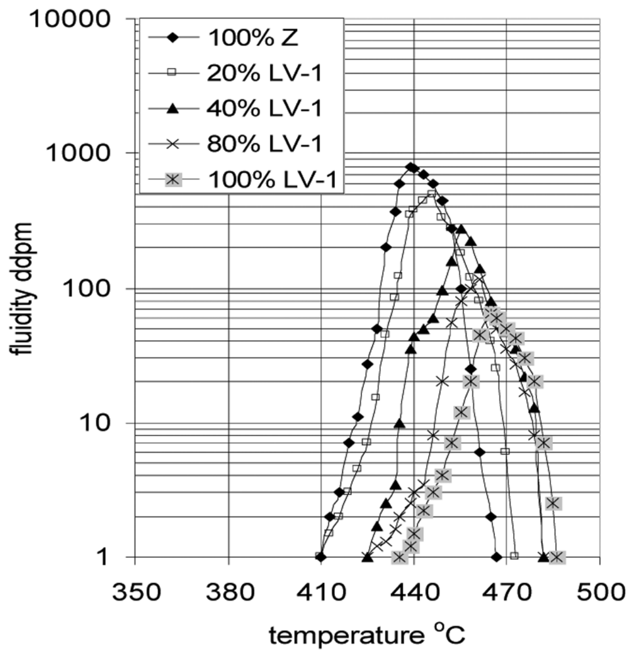

Figure 2—Plastometer results of Z and LV-1 coal blends

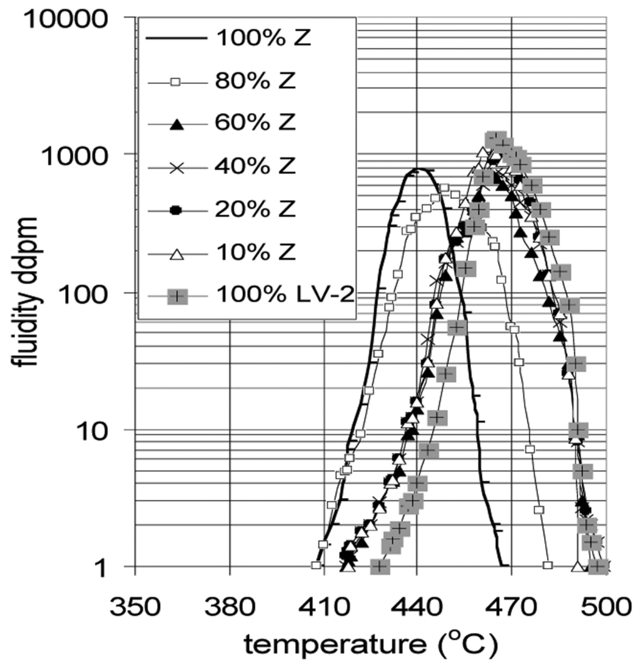

Figure 3—Plastometer results of Z and LV-2 coal blends

Evaluation of the plastometer tests on blends

Plasticity values of coal blends cannot be expressed as the arithmetic mean obtained from the blend components. This was observed in this study. When two different coals having different initial softening and resolidification temperatures were blended, the maximum fluidity of the blend was lower than the arithmetic mean. When this situation was investigated on plastometer curves, one of the components affected the other one, as expected, at two stages where coal showed insufficient fluidity. These stages were approximately the starting points of softening and of resolidification. At temperatures that both coals individually showed high fluidity, the fluidity of the blend was higher than the arithmetic mean.

A mathematical relationship between plastic properties of the coals and the plasticity of blends was attempted. The derived equations are given below and graphically represented in Figure 5. It was shown that maximum fluidity of a blend may be well defined mathematically. However, this relationship was obtained under certain conditions and cannot be generalized for all coal.

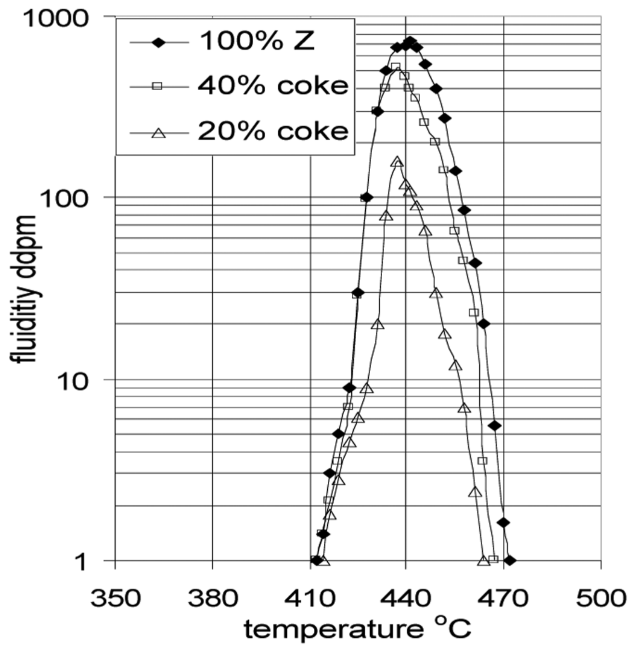

Figure 4—Plastometer results of Z blended with coke

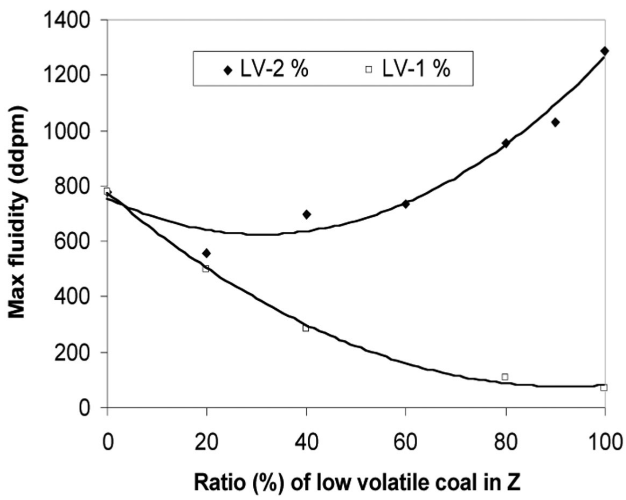

Figure 5—Mathematical definition of the effect of adding low volatile coals to the fluidity of Zonguldak coals

For Z and LV-2 blends:
Max. fluidity (ddpm) $=0.134x^2-8.3428x + 752.89$
$R^2=0.9558$ (correlation coefficient: 0.978)
For Z and LV-1 blends:
Max. Fluidity (ddpm) $=0.0829x^2-15.237x +774.47$
$R^2=0.9977$ (correlation coefficient: 0.999)

These results showed that, under certain conditions, the fluidity of blend of Z coal with low volatile good coking coal can be calculated with high sensitivity.

Conclusion

Zonguldak coal is a medium-ranked coking coal with 32 ±2% (daf) volatile matter and medium fluidity. As it is known when Zonguldak coal is used in coke making alone, the resulting coke does not have sufficient strength for use in modern blast furnaces. However, Zonguldak coal can be used in a suitable blend for coke making.

In our investigation, the plasticity characteristics of coal blends were not seen to be proportional to the plasticity characteristics of the individual coals used in the blends, but a relation between them was observed. However, this relation cannot be generalized to other coals or blends.

As is known, the fluidity of the low volatile coal must not be very low and its fluidity range too wide for the coal to be blended with Zonguldak coal. In fact, the low volatile coal must have a fluidity level that fills the gaps, as Zonguldak coal shrinks to overcome the side-effects of the different start and end fluidity temperatures.

Coal blend plastometer tests indicate that the best results obtained in balancing the blend fluidity were achieved with 20% to 50% of high volatile Zonguldak coal with low volatile coal. Although the plasticity ranges were very close to each other in this area, a rapid move towards the component's characteristics beyond this area was observed. Consequently, no more than 50% of Zonguldak coal should be used in a blend for use in the classic way of coke making.

References

1. ZIMMERMAN, R. *Evaluating and testing the coking properties of coal,* Miller and Freeman Publications Inc., San Francisco. 1979.
2. KEMAL, M. and ARSLAN, V. *Coal Technology* (In Turkish), Dokuz Eylul University, Izmir, Turkey. Publication No: 33. 2005.
3. GRAHAM, J.P. and WILKINSON, H.C. Coke quality and its relation to coal properties. Charge preparation and carbonization practices. *The Coke Oven Managers' Year-Book*, 1980.
4. CALLCOTT, T.G. Principles for blending coals. *BHP Technical Bulletin,* vol. 23 no. 2. November, 1979.
5. ANZU, F. The Study of blends from coking coal with high volatile matter in China. *Proceedings of the 39th Ironmaking Conference*. Washington Meeting. March 23–26, 1980.
6. VAN NIEKERK, W.H. and DIPPENAAR, R.J. Blast-furnace coke: A coal blending model. *Journal of the South African Inst. of Mining and Metallurgy*, February, 1991. pp. 53–61.
7. KOSINA, M. Effects of the properties and composition of coal blends on coke mechanical properties. *Fuel*, vol. 67. March, 1988.
8. LIN, M.F. and HONG, M.T. The effect of coal blends fluidity on the properties of Coke. *Fuel* vol. 65. March, 1986. pp. 307–311.
9. DUCHENE, B., STEILER, J., and ROUZAUD, B. Effect of rank and of interactions of coals on experimental coke properties. *Fifth Int. Iron and Steel Congress, Iron Making Proceedings*. vol. 45. Washington DC. 1986. pp. 211–219.
10. RALPH, J. and CHAMPAGNE, P.E. Petrographic characteristics impacting the coal to coke transformation. *Ironmaking Conference proceedings*, 1988.
11. PRICE, T.J., GRANSDEN, J.F., and KHAN, M.A. Effect of the properties of Western Canadian coals on their coking behaviour. *Iron Making Conference Proceedings*, 1988.
12. Turkish Hard Coal Enterprises Annual Statistics Report, 2005. (www.taskomuru.gov.tr)
13. RADKO, T. and MIANOWSKI, A. The influence of mineral material upon the coking characteristics of coal. *Fuel,* vol. 77, no. 6. 1998. pp. 503–507.
14. ZHU, T. *et al.* Study on the coking mechanism of coal and coal tar pitches. *1st International Cokemaking Congress*, September 13-18, Essen, vol.1-B. 1987.
15. CHARKER, F.E. Blast-furnace performance using high-ash coke. *Journal of the Iron and Steel Institute*. February, 1968.
16. GREGORY, J.A. and CRUMP, J.L. High strength coke from low rank coals. *BHP Technical Bulletin*, vol. 23, no. 2. November, 1979.
17. HOWER, J.C. and LLOYD, W.G. Petrographic observations of Gieseler semi-cokes from high volatile bituminous coals. *Fuel,* vol. 78. 1999. pp. 445–451.
18. BEXLEY, K., GREEN, P.D., and THOMAS, K.M. Interaction of mineral and inorganic compounds with coal. The effect of caking and swelling properties. *Fuel,* vol. 65. January, 1986.
19. DIESSEL, C.F.K. Carbonization reactions of inertinite macerals in Australian coals. *Fuel*, vol. 62. August, 1983.
20. FONG, W.S., KHALIL, Y., PETERS, W.A., and HOWARD, J.B. Plastic behavior of coal under rapid heating high temperature conditions. Fuel, vol. 65. P. 195. February, 1986.