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FORMED COKE ACTIVITIES WITH CANADIAN COALS

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FOREWORD

This report is being submitted for publication in the Proceedings of the 14th Biennial Conference of the Institute for Briquetting and Agglomeration, held in Hyannis, Mass. in August, 1975, in the format required by the Institute. Part of the material was presented at the Conference.

The activities discussed in the report relate to the new CANMET Energy Research Program Carbonization Processing Activity (EP2). The project was associated with both the New Coking Methods (EP2.2) and Assistance to Canadian Industry (EP2.5) elements of the Carbonization Project.

FORMED COKE ACTIVITIES WITH CANADIAN COALS

by

W.R. Leeder* and B.J.P. Whalley*

ABSTRACT

Preliminary results from CANMET and European formed coke laboratory tests suggest that most of Canada's coal, which is located in Western Canada, is not suitable as the sole binder in hot briquetting. Such coals are more suited to pitch binder processes and possibly as a source of char for a hot briquetting process. However, an Eastern fluid, high volatile bituminous coal is an excellent binder for hot briquetting and it is possible that small coal deposits and selected seams of high volatile coal in Western Canada may be of a similar quality. In hot briquettes made from metallurgical coke fines and Canadian and U.S. coking coals, the total dilatation of the binder coking coal was found to correlate with the crushing strength of the green briquettes.

INTRODUCTION

Formed coke is a "preformed" carbonaceous spherical agglomerate, briquette or extrusion that has undergone such thermal processings as hot briquetting (400-500°C), low temperature heat treating (450-600°C), carbonization (900-1000°C), oxidation (200-300°C), or some combination of these processes. The manufacture of metallurgical quality formed coke has been investigated for several years as an alternative to conventional slot-oven coke used in the iron blast furnace. A growing interest is being shown in formed coke processes, as indicated by the recent development of many pilot plants (1) and the announced construction of a commercial-scale plant by Sumitomo Metal in Japan (DKS Process) (2). The reasons for this interest include the ability of formed coke processes: to reduce carbonization pollution (1,3,4); to use cheaper, poor or non-coking coals (1,3,4); to be operated intermittently or continuously (1,3); to use finely-sized coals resulting from coal beneficiation, or ground for pipeline transportation (4); and to possibly lower capital and operational costs (1,5).

Recent results from full-scale blast furnace trials with formed coke have done much to dispel doubts about the technical feasibility of using it with, or as a substitute for, conventional metallurgical

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coke (6,7,8,9,10,11).

Process Types

The majority of formed coke processes can be classified into two categories based on the type of binder used in the spherical agglomeration, briquetting or extrusion forming step; 1) coking coal binder processes and 2) pitch binder processes.

The binder in coking coal binder processes is a bituminous coal that at about 450-500^{o}C normally exhibits so-called "fluid or plastic" (rheological) properties. A fluid high volatile bituminous coal is preferred. Typically the formed coke is 20 to 40 percent binder coal and the remainder char (a low-temperature carbonized coal). Spherical agglomeration, briquetting or extrusion, mixing and/or forming steps are done hot, at a temperature that is within the softening range of the binder coking coal, so that the plastic properties of the coal can be best utilized. After forming, the hot formed spherical agglomerates, briquettes or extrusions that are referred to as "green", can be heat-treated to improve their mechanical strength and/or to carbonize them (7,9,10). The heat-treating may not be necessary because "green" hot-formed briquettes, hereafter called "hot briquettes", charged directly to the blast furnace in some experimental trials, have compared favourably in behaviour to coked hot briquettes (6,10).

The pitch binder processes use coal and/or petroleum pitch to bind the briquette together using conventional briquetting technology. The principal component of the briquette is generally a char, coke, non- or slightly-swelling coal, or a mixture of these. The resulting green briquettes are usually heated in an oxidizing atmosphere to improve their mechanical strength and then carbonized to coke.

Some choice is available in binder usage since pitch has been used as a binder supplement in hot briquettes and coking coals are often an additive in pitch-bound briquettes.

Formed Coking for Canadian Coals

Generally higher quality and, until recently, the relative low delivered price of U.S. coals have traditionally made Canadian coking coals unattractive for Canadian steel producers. Thus, the Canadian steel industry faces several problems if it is to utilize Canadian coking coals. Some of these problems may be overcome by using formed coke processes.

The coal reserves of Canada, estimated at about 125 billion tons (12,13), are found mainly in the western and eastern parts of the country whereas the major steel mills are centrally located. Approximately 70 percent of the total coal reserves consist of medium and low volatile bituminous coals located along the Rocky Mountains (12, 13), from which about 12 [illegible]ion tons per annum are shipped to Japanese steel mills (14). [illegible] e east coast, high volatile coking coal deposits are mined in Nova [illegible]tia by the Cape Breton Development Corporation (DEVCO). Desp[illegible] adequate reserves of coking coals to serve Canadian needs, the [illegible] cost of transportation, especially from the west, has dictated [illegible] current use of approximately 8 million tons per year of U.[illegible] Appalachian coking coals by the steel mills in Ontario.

Although the delivered cost of Canadian coking coals to central Canada has recently become more competitive with that of their U.S. counterparts, quality is still a concern. The Western Canadian coals are characterized by their high finely disseminated ash content, their low sulphur content, and by their friability, whereas the eastern coals that occur in much smaller deposits are characterized by their low ash, high sulphur and high mining costs. Because of their friability, the run-of-mine western coals contain high percentages of fines and can be up to 50 percent < 0.42 mm (35 mesh). The fineness of the coal sizes, although it improves ash separation, causes problems in conventional coke-oven handling, storage and charging, and makes these coals more susceptible to oxidation. Formed coking processes can utilize such sizes and therefore would seem to be suitable alternatives to conventional cokemaking for processing these coals to coke.

Significant deposits of the non-coking lignite and sub-bituminous coals exist in the plains region of Alberta and Saskatchewan. Although these coals cannot be used in conventional coke ovens, economic incentives may exist to use them in formed coke processes. They are less expensive; they can be strip mined and, being geographically closer, would have lower transportation costs to the central plants than the Rocky Mountain coals.

CCRA/CANMET Formed Coke Objectives

The Canada Centre for Mineral and Energy Technology (CANMET), formerly known as the Mines Branch of the Department of Energy, Mines and Resources, Canada, has been interested in formed coking for many years; for example, it collaborated with the Canmore Mines Limited to develop a formed coke process in the early 1960's (15,16). It is presently co-operating with the Canadian Carbonization Research Association (CCRA), an organization whose members are drawn from the major Canadian steel and coal producers, in a formed coke research program. The major objectives of this program are:

1. To provide information to CCRA member companies and other interested organizations about current technology in the field.

2. To provide small-scale formed cokemaking and testing facilities for evaluating coals (especially Canadian ones) for potential use in formed coking processes. These facilities are intended for "screening" coal blends for formed coke prior to independent

evaluation by internationally recognized facilities.

3. To conduct an R and D program for investigating various aspects of the formed coking processes and their products.

This paper will discuss progress made towards the last two objectives. That is, developments in the formed coke facilities at CANMET and two European organizations using mainly Canadian coals are considered.

LABORATORY STUDIES

Laboratory-scale formed coke tests using coals of interest to Canadian coal producers and consumers have been carried out both at CANMET and in Europe. Three European organizations were chosen to assess the coals: Bergbau-Forschung (BBF), Eschweiler Bergwerks-Verein (EBV) for hot briquetting and Houillères du Bassin du Nord et du Pas-De-Calais (HBNPC) for a pitch-bound briquetting process. Results have been obtained from BBF and HBNPC from coking and non-coking coals.

This section describes the CANMET formed coking laboratory facilities and deals with CANMET experiments to characterize several variables affecting the quality of CANMET hot briquettes in order to relate their results to those of other organizations. The findings of preliminary CANMET investigations into the potential use of Canadian coals as the binder in hot briquettes are compared to those of the two European trials. The relationship between hot briquette coal binder petrographic analysis and the resulting briquette mechanical strength is considered.

CANMET Assessment of Hot Briquette Strength

Blast furnace coke must satisfy both chemical (sulphur, ash, etc.) and mechanical parameters. While chemical constraints normally can be satisfied by selecting and blending the coals to be coked, the mechanical parameter, referred to as coke "stability" in North America, generally cannot be reliably predicted from coal blend properties. Normally at least 250 kg of the coal is carbonized and 10 kg of the resulting coke evaluated using the ASTM coke tumble test (17). A coke stability of 55 is accepted by at least one steel industry as the desirable strength for conventional blast furnaces (4). Formed coke must meet similar quality standards if it is to be used as a conventional coke substitute. However, laboratory formed coke studies normally do not produce enough briquettes to carry out the ASTM Coke Tumbler Test and an alternative parameter such as the average crushing strength of several briquettes must be used.

In this paper only the crushing strength of hot briquettes and oxidized pitch bound briquettes will be considered in any detail. Fully carbonized hot briquettes will not be discussed. However, the crushing strength of a carbonized good quality hot briquette is often about twice that of the hot briquette (16,19).

CANMET hot briquette crushing strengths were determined between parallel plates closing at a rate of approximately 0.127 cm/min. A value of 14,000 kPa (kilopascals; PSI x 7 ≈ kPa) was chosen by the authors as acceptable crushing strength for the 2.86 cm diameter by about 3.15 cm high hot briquettes made under optimal experimental conditions by the CANMET manual batch-operated method. This value was derived from BBF crushing strength criteria and an earlier relationship between briquette crushing strengths and their corresponding ASTM Tumble Test stability indices (18,20). The acceptable level (14,000 kPa) could be altered in the future to reflect new evidence.

CANMET Facilities and Procedures

CANMET, in co-operation with the CCRA, is developing laboratory and pilot development unit facilities with the objective of providing a means to assess the formed coking potential of Canadian coals by either hot briquetting or pitch binding processes. To date the principal efforts at CANMET have gone into developing laboratory-scale manual batch-operated and automatic continuously operating hot briquetting facilities. These are now in operation. Pilot-scale continuous hot briquetting facilities are presently nearing completion.

The manual batch-operated facility consists of a muffle furnace to dry and preheat a blend of the char and binder coal, a fluidized bed unit to heat the blend into the plastic range of the binder coal and a heated die in which the briquette is formed. Typically 13 and 7 g of the char and binder coal are mixed in a beaker and placed in a 300°C muffle furnace for about 30 minutes. Tests have shown that oxidation of the binder coal dried in air is minimal since briquette crushing strengths decreased only 5 to 10 percent as compared to drying in nitrogen. The dried, preheated blend is poured into a hot 5 cm diameter electrically heated fluidization unit (using nitrogen as the fluidizing gas) and heated to about 400-450°C. The mixture is transferred manually to a heated (350-450°C) tool steel 6.45 cm^2 (1 $in.^2$) area cylindrical die and compacted using a manually operated press. The die has been constructed so that a briquette is pushed out of the bottom and is removed from a slot by hand.

The automatic continuously operating facility consists of a fluidized bed mixer-feeder described at the last IBA Conference (21) connected to a heated 6.45 cm^2 cylindrical die and automatic press custom-made by Hovey and Associates (Ottawa, Ontario) from a conceptual design of the authors. This automatic facility heats coal and char sized from 0.25 to 0.07 mm (typically to 300 and 700°C), in separate fluidized beds, before transferring them to a heated fluidized bed mixer. After 15 sec mixing, the blend is transferred pneumatically to the Hovey press where it is hot briquetted. This facility is shown schematically in Figure 1. It has a variable rate of production but is currently producing about one 20 g briquette every 2 minutes with an output of about 150 briquettes per day. The automatic system has an advantage over the manual system in being able to produce many more briquettes under consistent and repeatable experimental conditions. However, it has the disadvantage at its present state of development of using only a restricted size range of materials to permit good fluidization and pneumatic transport in the system.

If desired, hot briquettes can be heat-treated (450-650°C) or carbonized (800-900°C) in a specially constructed 1.07 m high and 0.20 m diam fluidized sand bed. The bed is heated by external electrical heaters and fluidized with nitrogen. Consistent and satisfactory heat-treating results are obtained by lowering a 13 cm square wire mesh cage (1.2 cm holes) containing 5-8 briquettes into the hot fluidized sand and then fluidizing the sand 15 seconds in every 3 minutes. Intermittent fluidization prevents unnecessary agitation of the briquettes but maintains the temperature of the sand bed.

CANMET Results - Hot Briquetting Variables

Laboratory formed coking equipment, especially that for hot briquetting, is not available in standardized form and for the most part had to be designed and built as required. It is well known that the laboratory-scale equipment designed to simulate industrial processes is likely to measure relative rather than absolute effects of variables and, because of a lack of uniformity of equipment and technique, it is often difficult to reproduce the results of experiments in other laboratories. Because of this consideration and the unpredictability of the initial CANMET results, some of the factors affecting hot briquetting using CANMET equipment will be briefly considered.

Temperature is a most important variable in hot briquetting. The temperature and rate of heating of the char/binder coal blend affect greatly the plastic properties of the binder coking coal that can be measured with a Gieseler Plastometer (22) or a Ruhr Dilatometer (23) or by determining the coal Free Swelling Index (FSI) (24). The influences of blend heating conditions and briquetting temperatures on the crushing strengths of hot briquettes made by the manual laboratory procedure appear in Figures 2 and 3. The fluid bed is used not only to heat uniformly the dry 300°C char and binder coal blend, but it also imposes a controllable rate of heating up to the fluid range of the binder coal. The wall temperature of the fluid bed unit is preset using coke fines that are removed before introducing the blend to be briquetted. The rate of heating of the char and binder coal blend then becomes a function of the bed wall temperature. The temperature of the blend was followed with a thermocouple so that it could be briquetted at a predetermined temperature or time.

The results in Figure 2 indicate that the best conditions for heating a < 0.6 mm 300°C blend of 70 percent by weight of semi-anthracite char with 30 percent hvb Eastern Canadian coking coal in the fluid bed occurred when the fluid bed wall was at about 470°C. This corresponds to the upper end of the Gieseler Plastometer fluid range of the binder coal. The best hot briquette strengths occurred when the softened binder and char mixture was removed at about 435°C, which corresponds to the maximum Gieseler plastic characteristics of the binder coal. The rate of temperature increase at the point of maximum crushing strength, while not available from the data in Figure 2, was of the order of 40°C/min. A rate of 30°C/min is considered the threshold rate to obtain the maximum fluid properties from a coking coal (25). It can be concluded, as might be expected, that the best hot briquetting results were obtained at conditions that allow the maximum plastic properties of the binder coal to be attained.

Figure 3 shows how the temperature of the briquetting die influences the strength of hot briquettes made from metallurgical coke fines and Eastern Canadian coal (70 and 30 percent by weight respectively). The best briquetting temperature was just below the plastic range of the binder coal. There appears to be a range in die temperature of approximately 100°C over which changes of about 10 percent in hot briquette crushing strengths were observed.

The influence of the size consist of the blends being hot briquetted has been shown to be important to the resulting laboratory-scale briquette crushing strength (19). Since the CANMET automated laboratory facility is presently restricted to using from 0.25 to 0.07 mm components, whereas the manual method can use a wide size range, the influence of size consist was studied using the manual method. The results appear in Figure 4. Two screened components of metallurgical coke, to be referred to as "coarse" and "fines", were blended in different proportions and hot briquetted with 30 percent by weight of < 0.6 mm Eastern Canadian hvb binder coal. Details of the coke size appear in Figure 5. The optimum crushing strength of the hot briquettes corresponded to a coke or char blend containing between 20 and 40 percent of the "fines". This range is outlined by the darkened area in Figure 5. The size of char used in the BBF European laboratory hot briquetting study with Canadian coals, also fell within this envelope (18).

The results in Figure 4 indicate that the crushing strength of hot briquettes made with 30 percent Eastern Canadian hvb binder coking coal and 100 percent of the "fine" char (5600 kPa = 800 PSI) is considerably lower than the maximum strength obtained with the optimal blend of the "coarse" and "fine" sizes (14,000 kPa). The size distribution of the "fines" approaches that of the materials used in the automatic laboratory facility. This suggests the minimum acceptable crushing strength of hot briquettes from the automatic laboratory facility should be about 5600 kPa since the minimum acceptable strength for hot briquettes made under optimum conditions was considered to be 14,000 kPa.

Briquetting time and pressure have been shown to affect hot briquette crushing strength (19,26). Preliminary tests to investigate the performance of the automated laboratory facility included such an investigation. The results appear in Figure 6, where lines of equal crushing strength are indicated for given briquetting times and pressures. A blend of 0.25 to 0.07 mm semi-anthracite char (2.5 percent volatile matter) and Eastern Canadian high volatile bituminous coal was used. This blend was preheated and mixed at 400 ± 5°C in the fluid bed part of the facility, transferred through a hot stainless steel tube so that it arrived at the die at about 420°C and briquetted with the die internal temperature at 455 ± 10°C. The length of time necessary to achieve an acceptable crushing strength of about 5600 kPa for the 0.25 to 0.07 mm material varied from approximately 10 sec at 56,000 kPa to 20 sec at 28,000 kPa. Although these briquetting times are unrealistically long when compared to a roll press, they indicate the conditions to make a hot briquette of acceptable crushing strength with the automated laboratory facility and these strengths can presumably be correlated to those produced in other equipment.

<u>Canadian Coals as Hot Briquette Binders</u>

Tests to consider the applicability of Canadian and U.S. coals to hot briquetting were carried out at CANMET and under the CCRA auspices at BBF in Germany (18). Several char components made from sub-bituminous, bituminous and semi-anthracite Western Canadian and a high volatile bituminous Eastern Canadian coal were successfully used in this BBF study.

In preliminary CANMET tests to assess the effects of binder coal rank and types of char, inconsistent results were often found. For example, hot briquette crushing strengths could vary by a factor of two in tests using the same Eastern Canadian hvb bituminous binder coal with each of three similarly prepared Western Canadian sub-bituminous coal chars. Because of this problem a procedure was worked out to isolate the influence of the binder coal from the char by using a uniform size consist of metallurgical coke fines as the char component. With the "char" variable held constant, it was then possible to consider the quality (crushing strength) of hot briquettes in terms of the binder coal.

While investigating the application of Canadian and American binder coals to hot briquetting, a method of predicting green briquette strengths by measuring another parameter such as the microscopic composition or dilatation of the binder coal was sought. The fluid properties of coking coals are determined by that part of the coal that melts when the coal is heated. The majority of the melting material in coal is called vitrinite and this can be quantitatively determined for a coal sample using the petrographic technique of a reflected light microscope. Since vitrinite represents most of the "glue" in a softened coking coal, it seems reasonable that a relationship should exist between the percentage of vitrinite in the hot briquette binder coking coal, expressed as a percentage of the total briquette, and the resulting crushing strength. The results appear in Figure 7. Using data from Lehmann's report (18) a relationship was found that is evidently linear, provided that the coals were not oxidized. Figure 7 suggests that about 22 percent by weight of a hot briquette should be unoxidized vitrinite to yield an acceptable crushing strength.

Since the effects of oxidation on coal fluidity cannot as yet be quantified from a petrographic analysis, a direct test of binder coal fluid properties, such as dilatation, was studied. This property is of considerable interest with respect to Canadian coals because although coking coal Ruhr dilatation results have been found to correlate with their resulting coke quality (27), this test often failed to predict this property for Western Canadian coals. Many Western Canadian coal samples that have no dilatation and therefore would not be expected to make coke, have yielded excellent quality coke in a technical-scale oven (28). Since a relationship often exists between the crushing strengths of hot briquettes and their carbonized product (coke), it might be expected that the dilatation of Western Canadian binder coals would not be a parameter indicative of hot briquette crushing strengths.

Preliminary results from tests to explore the relationship between Canadian and American binder coal total dilatations and CANMET manually produced hot briquette crushing strengths appear in Figure 8. These briquettes were made with 20, 30 and 40 percent of < 0.6 mm binder coals and a coke component whose size analysis fell into the grey area in Figure 6. The briquetting temperature conditions were optimum for each binder coal. The acceptable crushing strength was considered to be 14,000 kPa. The trend in Figure 8 agreed with a similar plot (Figure 9) derived from data taken from the BBF report (18). A number of observations arise from Figures 8 and 9.

1. The results from both laboratories had similar trends even though the experimental briquetting procedures differed. As well, the total dilatation necessary for the binder coal to give the laboratory hot briquette an acceptable crushing strength was between 100 and 150 percent in both laboratories.

2. The spread in the BBF crushing strength results in Figure 9 for a given binder coal and concentration, was due to the use of different chars. The results in Figure 8 where the CANMET manual method was used to make hot briquettes with a consistently sized metallurgical coke as the char component, eliminated this type of spread in results. The detailed influence of char on hot briquette strength is an area CANMET will consider in the future.

3. In both studies, the relationships between the total dilatation of the U.S. and Canadian binder coals with hot briquette crushing strengths appear to follow the same trend. It would seem that the Ruhr dilatation of either group of coals can be used to predict the ability of any given binder coal to yeild an acceptable hot briquette crushing strength and future studies should clarify this point with respect to coke hot briquettes. This was not expected in light of the inability of Ruhr dilatation to predict the coking potential of Western Canadian coking coals.

4. Most Western Canadian bituminous coals are of medium or low volatile rank and their total dilatations are normally less than 100 percent. From Figures 8 and 9 it can be seen that they would yield an unacceptable quality hot briquette if used as the sole binder. Pitch or tar additions may be necessary to improve the binding properties of these low fluid coals in hot briquettes. Such an attempt was made in the BBF laboratory-scale studies but it met with little, if any, success (18). Such additions may be more beneficial on a larger pilot plant scale where there is more careful control over such experimental variables as the mixing and curing of the char and softened coal mixture. It may be concluded that most Western Canadian bituminous coals would be unsuitable as the sole binding agent in hot briquettes, although they may be utilized as the char component. Select seams of higher fluid hvb coals do exist in Western Canada and it is possible these could be used as a hot briquette binder.

Pitch Binder Tests

Pitch-bound briquette tests carried out at HBNPC using the same coals as in the BBF hot briquetting tests, gave quite different results (29). HBNPC makes briquettes with a pitch binder and a blend of coking coal with a larger protion of a low- or non-swelling coal. The briquettes are then oxidized and heat treated to improve their mechanical and high temperature properties. The results of the HBNPC laboratory tests appear in Table 1 (29). Generally, briquettes made from a fluid coal as indicated by its high FSI (e.g. 6½) were poor. Coals with low or no FSI tended to yield acceptable oxidized briquettes. The Eastern Canadian coal that gave the best results as a hot briquetting binder coal could only be tolerated in very limited portions in the HBNPC blend and probably should not be used at all. These conclusions are tentative since the treatment of the briquettes included only oxidation and not a final high temperature treatment.

SUMMARY AND CONCLUSIONS

1. CANMET has developed laboratory-scale hot briquetting facilities and procedures that make hot briquettes with crushing strengths similar to those found in other laboratories. The influence of such variables as temperature conditions, char size, briquetting pressure and time on birquette strength corresponds to the results from other organizations.

2. Canadian coals were used at CANMET and in European laboratories to determine how they might be used in formed coke processes. Preliminary hot briquetting results from CANMET and BBF indicate a similar relationship between the binder coal total Ruhr dilatation and the resulting briquette crushing strength. Binder coals with total Ruhr dilatations of less than about 100-150 percent yielded unacceptable hot briquettes. This includes the majority of Canada's coals that are of low and medium volatile bituminous rank located in or near the Rocky Mountains. Acceptable hot briquettes may be made on a commercial-scale with some of these low fluid coals if tar or pitch additives are used as well. In the dilatation versus crushing strength relationship, it was also noted that the Canadian and U.S. binder coking coals behaved similarly. The Eastern Canadian highly fluid, high volatile coking coal has been shown to be an excellent binder coal for hot briquetting and it is possible that selected seams of Western Canadian high volatile coal can be used to make hot briquettes of acceptable quality. Acceptable char for hot briquettes can be made from Canadian coals. Preliminary laboratory pitch-bound formed coke tests carried out at HBNPC indicated that the low or non-swelling Western Canadian coals were suited to this type of process. Use of large percentages of the higher swelling medium or high volatile bituminous Canadian coal gave poor quality oxidized briquettes.

3. Quantitative relationships between hot briquette crushing strength and standard laboratory tests of coking coal properties, such as the unoxidized binder coal vitrinite content or total dilatation, should eliminate much expensive and time-consuming experimental work in selecting coals for formed coke production.

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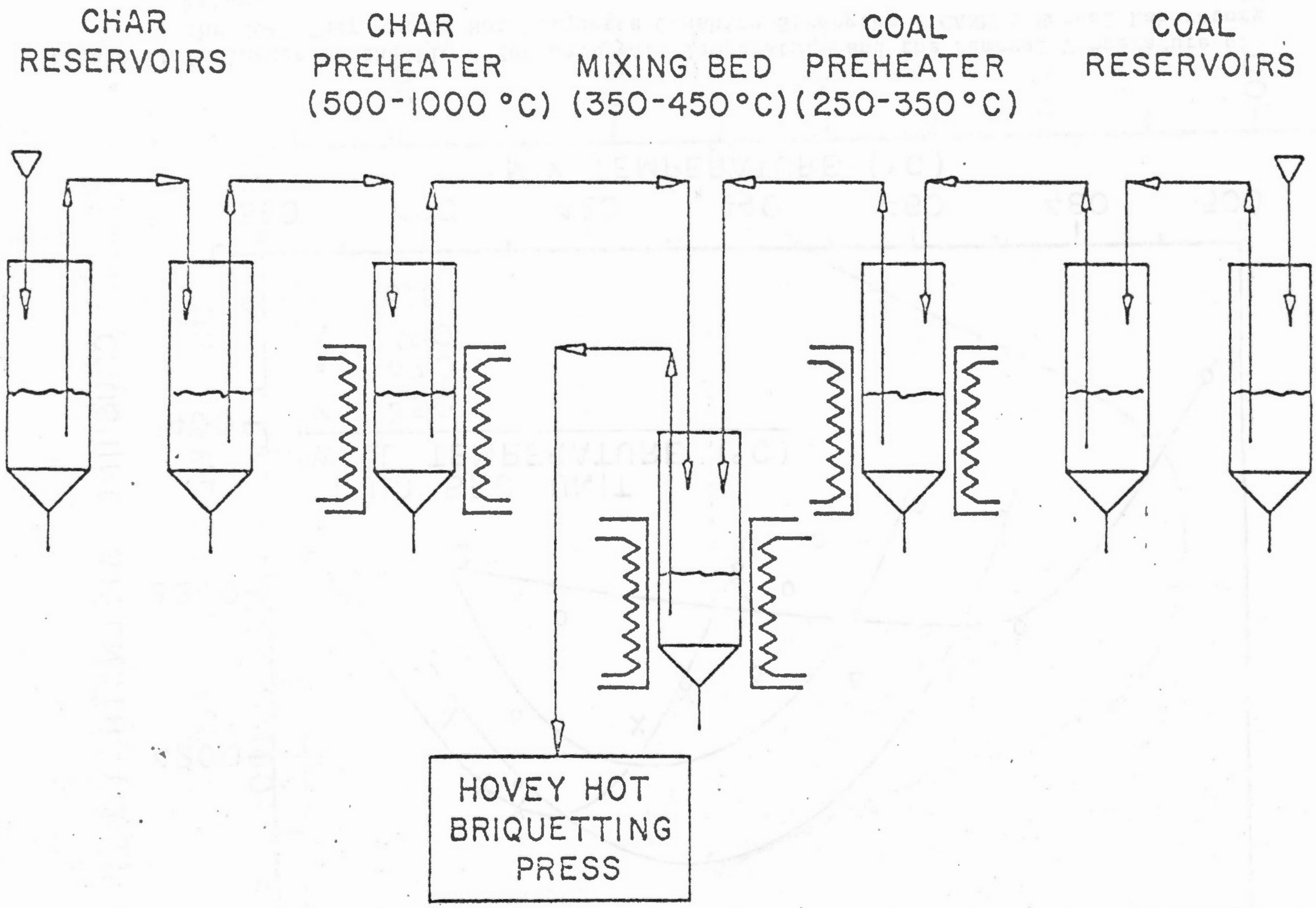

Figure 1: Schematic of the CANMET Automatic Laboratory Hot Briquetting Facility

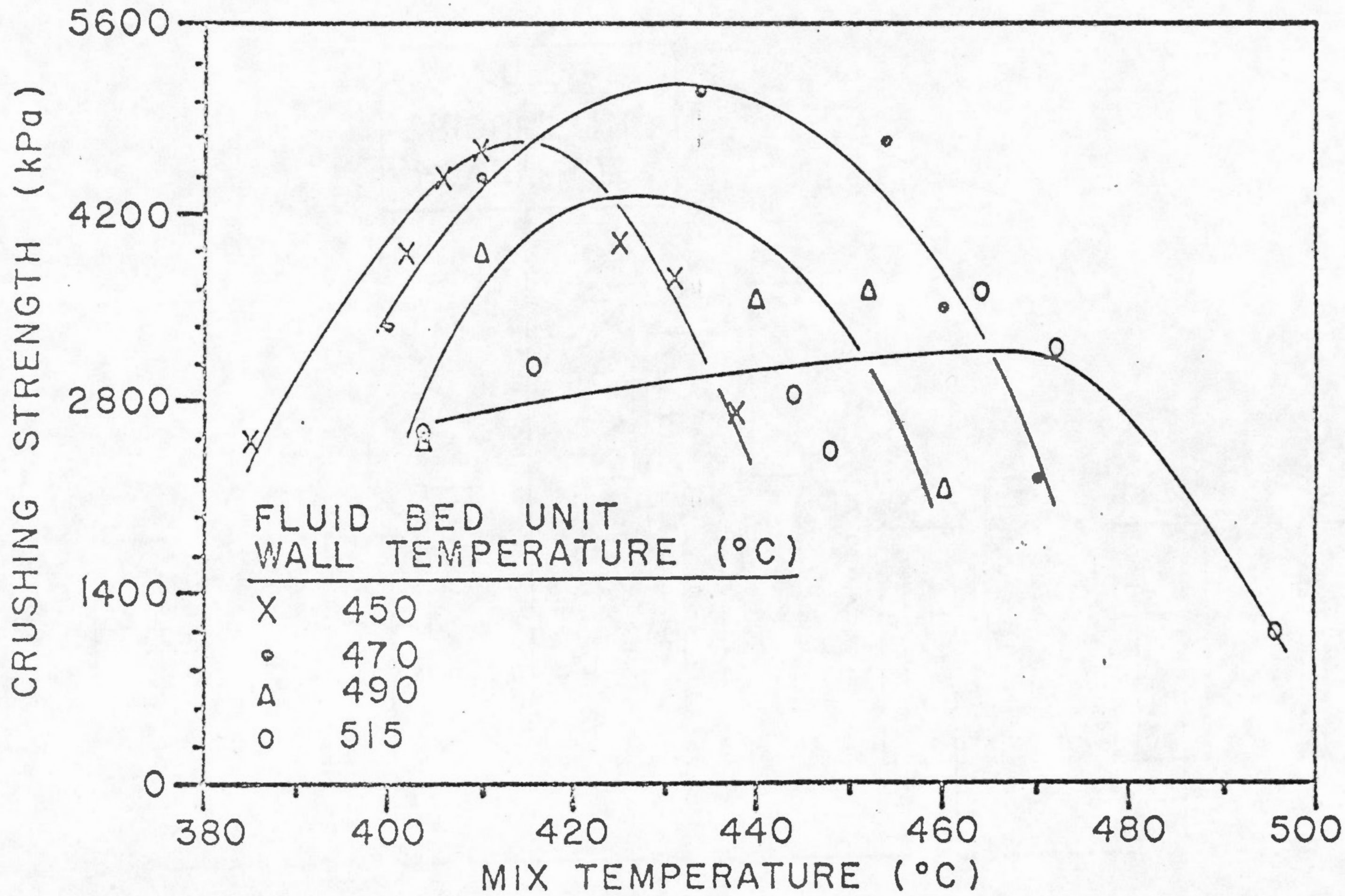

Figure 2: Influence of the Fluid Bed Unit Wall Temperature and the Removal Temperature of the Coal/Char Mix on Hot Briquette Crushing Strengths - CANMET Manual Laboratory Method.

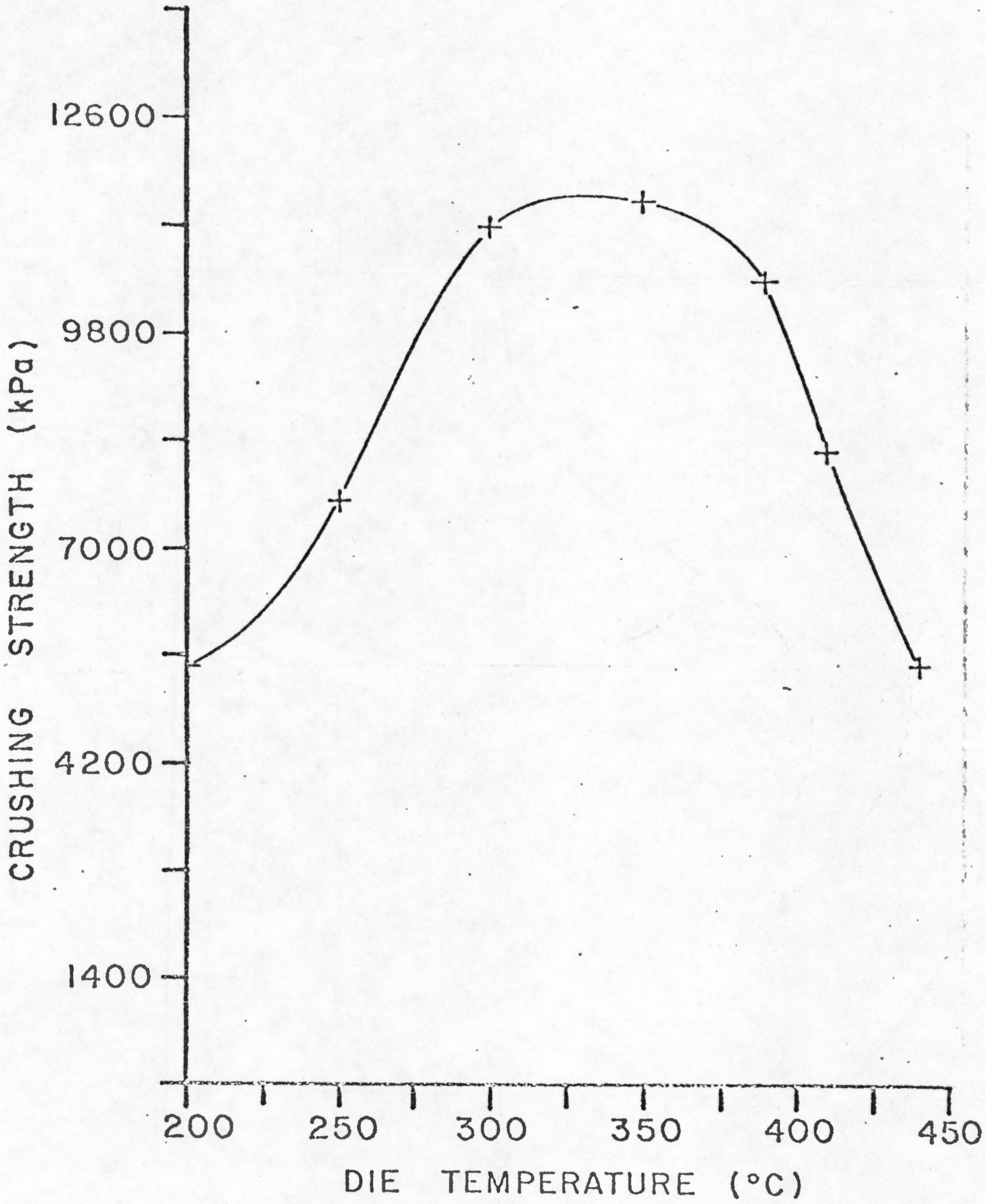

Figure 3: Influence of Briquetting Die Temperature on Hot Briquette Crushing Strengths - CANMET Manual Laboratory Method

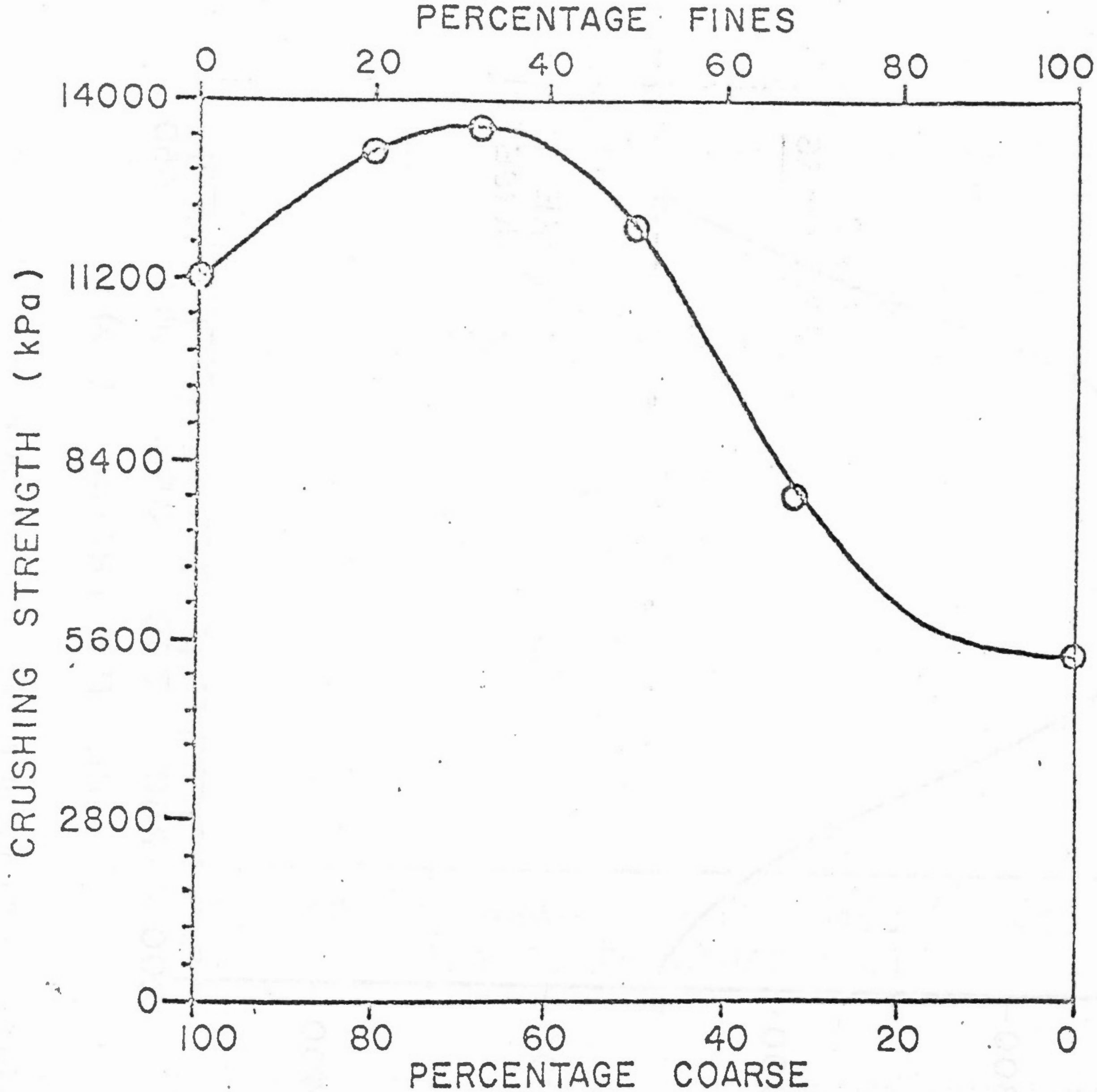

Figure 4: Influence of Char Size on Hot Briquette Crushing Strengths - CANMET Manual Laboratory Method (see Figure 5 for details of the char sizes)

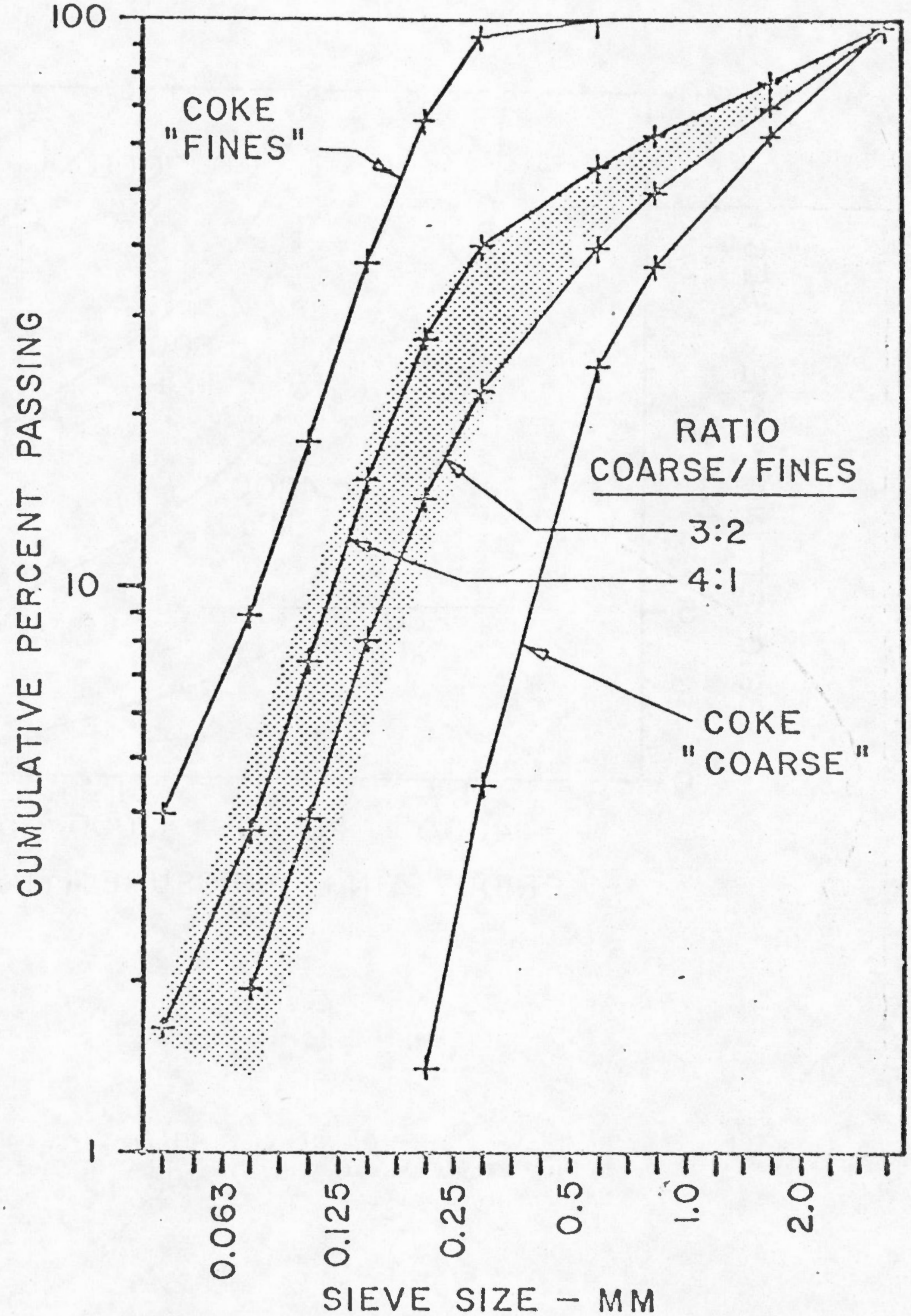

Figure 5: Size Analysis of the Metallurgical Coke "Fines" and "Coarse" Components and Two Mixtures. Use of Coke Sized in the Shaded Area Yields the Highest Crushing Strength Hot Briquettes - CANMET Manual Laboratory Method

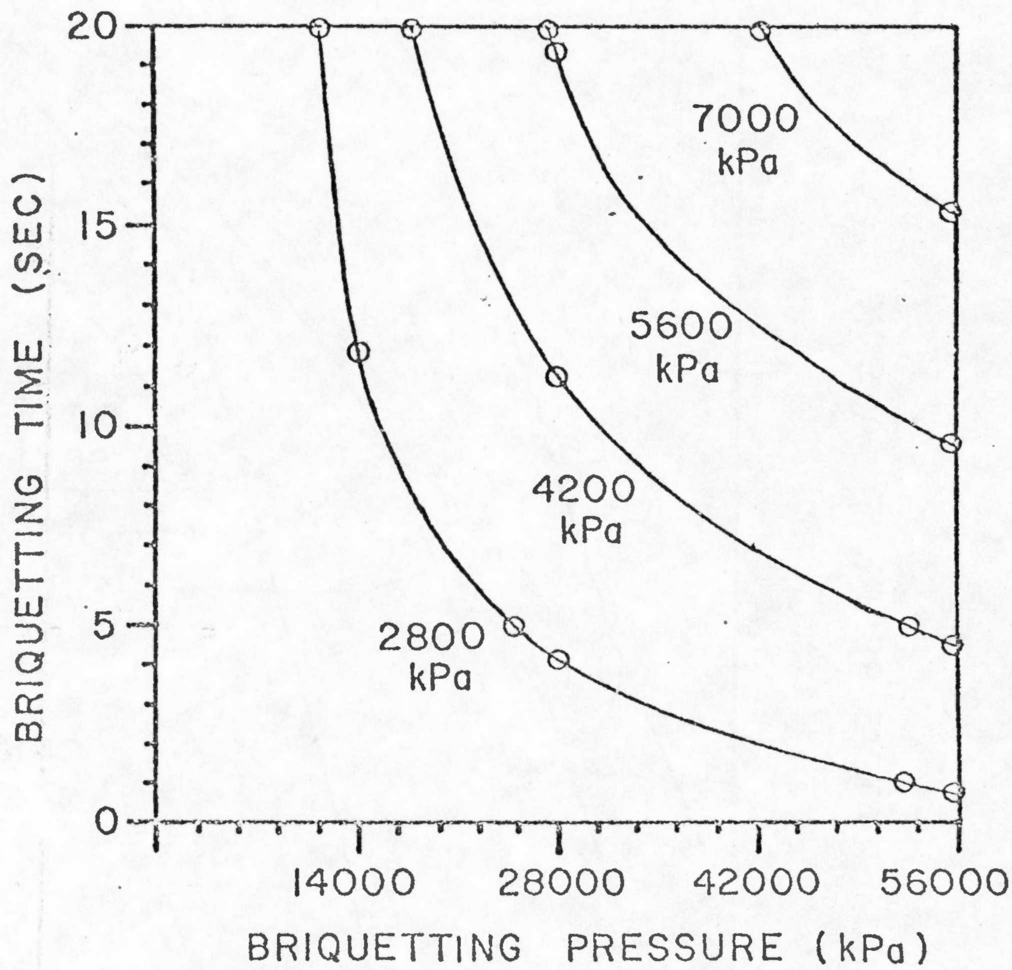

Figure 6: Equivalent Crushing Strength Lines Versus Hot Briquetting Pressure and Time - CANMET Automated Laboratory Facility

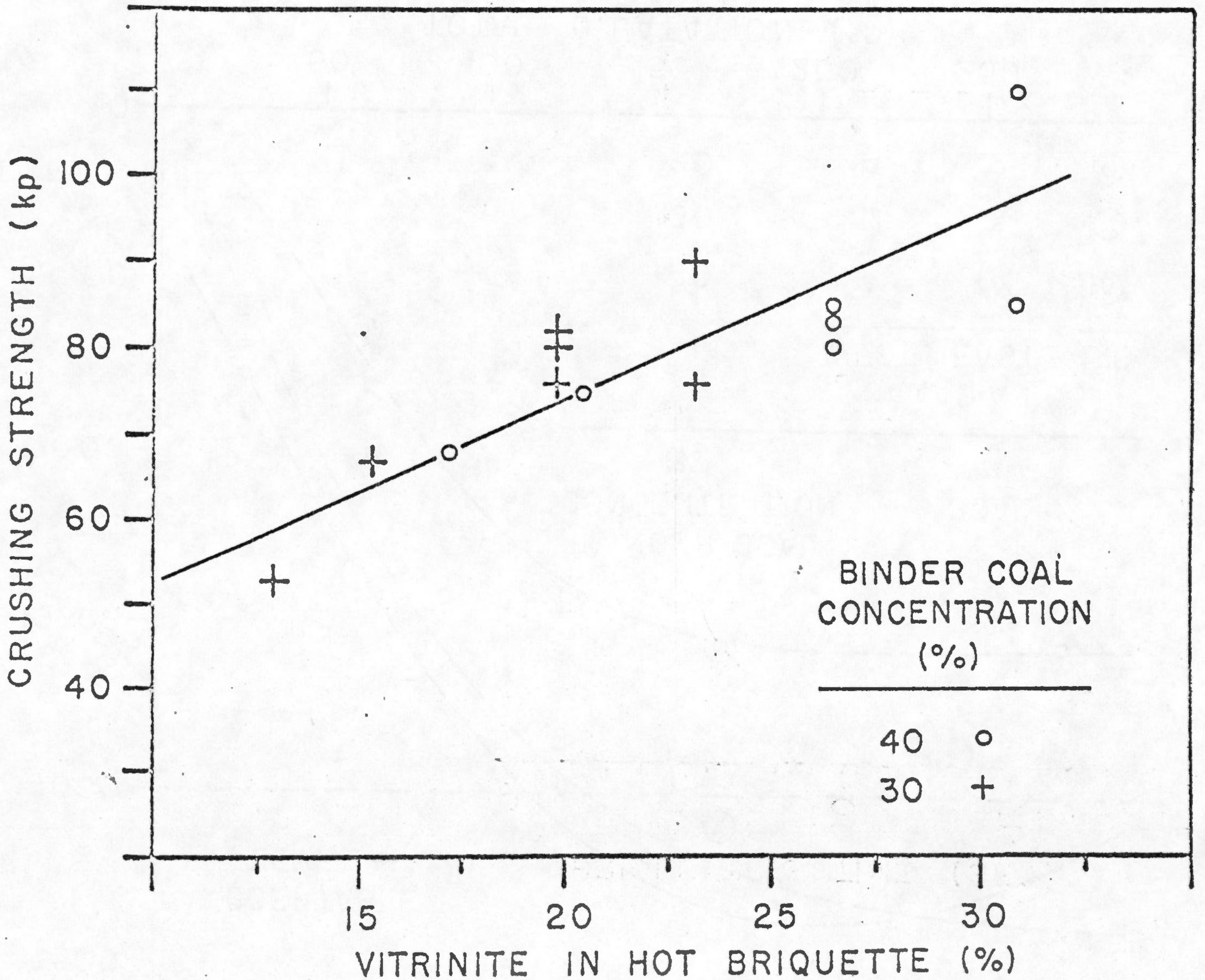

Figure 7: Influence of Binder Coal Vitrinite Content, Expressed as a Percentage of the Total Briquette, on Hot Briquette Crushing Strengths - Plotted from BBF Laboratory Method Data (18)

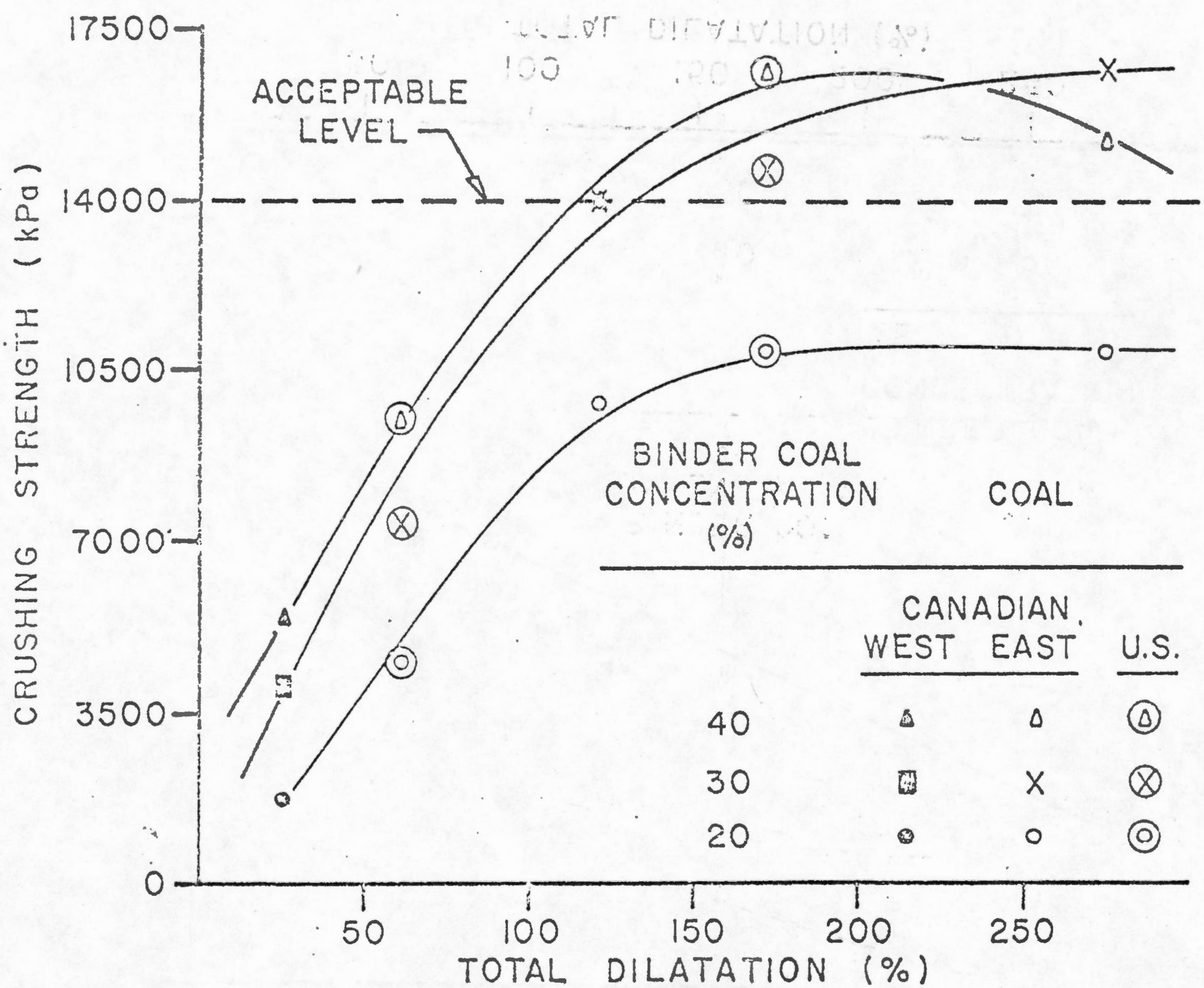

Figure 8: Influence of Binder Coal Total Dilatation (Contraction Plus Dilatation) and Concentration on Hot Briquette Crushing Strengths - CANMET Manual Laboratory Method

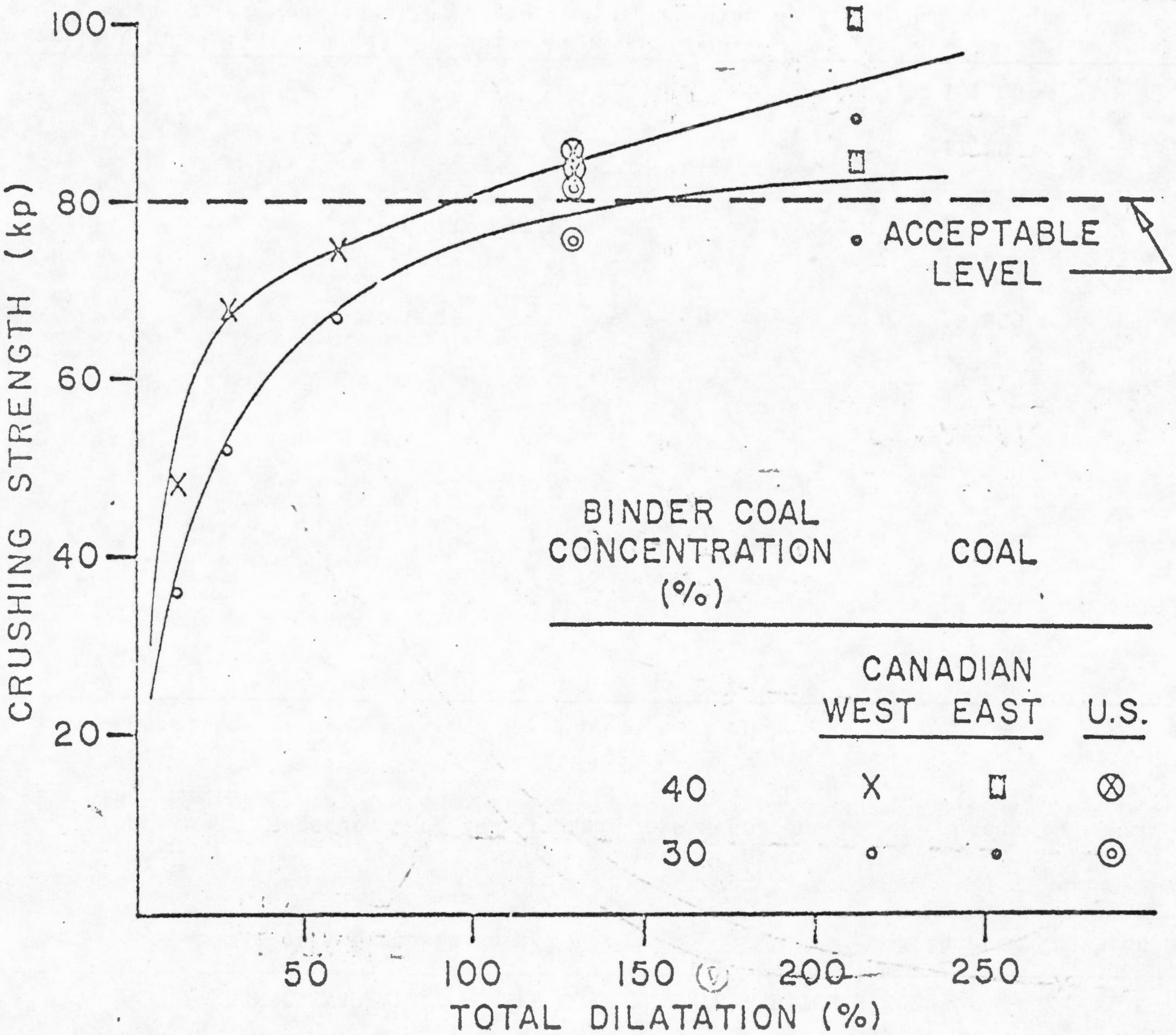

Figure 9: Influence of Binder Coal Total Dilatation (Contraction Plus Dilatation) and Concentration on Hot Briquette Crushing Strengths - Plotted from BBF Laboratory Method Data (18)

TABLE 1

HBNPC LABORATORY FORMED COKE RESULTS - PITCH BINDER[1/]

Coal	Western Canadian Semi-anthracite	Western Canadian Coking Coals #1	Western Canadian Coking Coals #2	Western Canadian Coking Coals #3	Eastern Canadian hvb	Briquette Crushing Strength[2/] Green (kPa)	Briquette Crushing Strength[2/] Oxidized[3/] (kPa)
F.S.I.	0	5½-6	6½	1½-2	8-8½		
Rank[4/]	Semi-anthracite	mvb	mvb	hvBb	hvb		
	80	-	-	-	20	8,000	16,000
	85	-	15	-	-	13,900	> 25,000
	80	20	-	-	-	10,200	> 25,000
	-	-	25	75	-	7,500	15,000
	-	-	35	65	-	8,500	18,500
	-	-	40	60	-	7,000	25,000
	-	-	100	-	-	8,500	0
	-	-	50+50 Petroleum Coke		-	11,500	0
	100	-	-	-	-	11,000	25,000
	50	-	20	30	-	10,500	21,000

Briquette Composition (%)

1/ 9% coal-tar pitch with a softening point of about 70°C.
2/ Crushing strength between parallel plates of a 3 cm diam by 2.5 cm high briquette
3/ Anything greater than 12,500 kPa is considered acceptable.
4/ See reference 30 for definitions of coal rank.