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FORMED COKE PROGRAM

INFLUENCE OF SIZE CONSIST, VOLATILE MATTER AND ASPHALT (PITCH)

(PROJECT NO. EP2.2.02)

CONTENT IN THE CRUSHING STRENGTH OF PITCH BOUND BRIQUETTES - PRELIMINARY STUDY

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by

W.R. Leeder*, M.J. Malette** and M.M. Silver**

INTRODUCTION

Formed coke is a preformed and thermally treated carbonaceous agglomerate such as an extrusion, spherical agglomerate or briquette that can be used as a substitute in the iron blast furnace for conventional metallurgical coke produced in slot-type coke oven batteries(1,2,3,4,5,6). Interest in formed coke processes exists because unlike conventional slot-type coke oven battery operations, they can utilize non-coking and/or finely sized coal in a continuous, cleaner and possibly less expensive process(7,8,9,10). Consequently, more than twenty formed coke processes that use several processing methods have been developed, including at least one commercial-scale plant(7,11). These processes can be classified into two groups; cold forming with a pitch binder; and hot forming with a coking coal binder.

Presently, approximately ninety percent of the coking coals used to make metallurgical coke in Canada are imported from the United States because of their generally higher quality and until recently a lower delivered price than their Canadian counterparts. Formed coke processes would allow Canadian coke-makers to utilize only domestic coals that otherwise could not be used or would cause severe operating problems in conventional coke-making. Such an objective is also consistent with the present policy of achieving Canadian energy self-reliance (12,13).

The Canada Centre for Mineral and Energy Technology (CANMET), formerly the Mines Branch, Department of Energy, Mines and Resources, has been interested

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in such processes for some time. Early studies involving pitch-bound briquettes culminated in the development of a commercial process in collaboration with the Canmore Mines Limited. Current CANMET studies have focused on hot briquetting[14,15,16] but recent worldwide advances in pitch binder processes and the desire for Canadian energy self-sufficiency have again made pitch binder formed coke processes of interest to CANMET

This report presents a preliminary study carried out by the Canadian Metallurgical Fuel Research Laboratory (CMFRL) to investigate some of the variables associated with formed coke processes using pitch binders. Pillow-shaped "green" briquettes were made with Canadian coals, coal chars (a low-temperature carbonized coal) or combinations of both, and a petroleum asphalt (pitch) binder, to simulate the more advanced FMC and Houillères du Bassin du Nord et du Pas-de-Calais (HBNPC) pitch-bound briquetting processes[3,17]. The green briquettes were hardened by oxidation in air at 240°C for 2 hours, then heat-treated in nitrogen at 550°C for 1 hour to devolatilize and further strengthen the briquettes. The preliminary results of the influence of coal and char size consist, volatile matter and pitch content on the crushing strengths of the green, oxidized and heat-treated briquettes will be discussed.

The results presented in this report relate to the CANMET Energy Research Program Carbonization Project (EP2). The investigation was part of the Formed Coke Variables Commitment (EP2.2.2) of the New Coking Methods Work Element (EP2.2).

EXPERIMENTAL

Materials

The pitch used as the briquette binder was a petroleum asphalt that had an ASTM ring and ball apparatus softening point of 74°C[18]. The coals used in the briquettes were a Sydney Steel Co. Ltd. (Sysco)hvb coking blend, Fording Coal Limited mvb coking coal, McIntyre-Porcupine Limited lvb coking coal and Canmore Mines Limited semi-anthracite. The chemical and thermal rheological analyses of these coals appear in Table I, together with the proximate and sulphur analyses for the Forestburg sub-bituminous and Luscar lignite coals used to prepare chars.

The Forestburg sub-bituminous coal was charred by carbonizing it in a steel box inserted in the CMFRL 30-lb slot-type coke oven until a charge centre temperature of 750°C was attained. The Canmore semi-anthracite char was prepared in an electrically heated rotating retort at a temperature of 870°C[19]. A commercial Luscar lignite coal char and discarded metallurgical coke fines obtained from the Electric Reduction Company Limited (ERCO) were also used. The proximate and sulphur analyses of the chars and coke fines appear in Table 2. The size distributions of the briquetted materials are shown graphically in Figure 1.

Procedure

Briquettes were made by the following procedure. Two to nine kg of char and/or coal were placed in a No. 1 Day Cincinnatus Mixer, the mixer started and about 500 g of water added. Steam was introduced into a steam jacket around the mixing chamber to bring the temperature of the water/coal and/or char mixture to between 50-70°C. Melted asphalt was slowly poured into the blending mixture until the required weight was added. Mixing was continued for 30 minutes with additional steam being introduced directly into the mixing chamber. After this, the warm mixture was placed in a tub and allowed to cool for 5 to 10 minutes before large scoops of it were poured down a 10 foot vertical chute into an operating Komarek-Greaves double roll press where it was formed into 3.8 x 3.8 x 1.4 cm pillow-shaped briquettes weighing 11 to 15 g. The auger feeder for the roll press was not used and consequently no precompaction of the mixture occurred before briquetting. The briquettes were allowed to cool and stored in plastic bags. These briquettes are referred to as "green".

Oxidation to harden 35 to 40 green briquettes was accomplished by heating them for 2 hours at 240°C in a muffle furnace. Air, preheated to the temperature of the furnace, was allowed to flow slowly over the briquettes. A thermocouple was positioned above the briquettes to monitor temperature and detect any combustion. After oxidation the briquettes were allowed to cool under ambient conditions.

Ten to twenty of the oxidized briquettes were heat-treated for one hour at 550°C in a specially constructed 1.07 m high and 0.20 m diameter 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 cubic (13 cm on a side) wire mesh cage (1.2 cm holes) containing the briquettes into the hot fluidized sand and 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.

The crushing strengths of the green, oxidized and heat-treated briquettes were obtained using a Houndsfield Tensometer with a compression accessory. Briquettes were crushed between the parallel flat ends of two 25 mm diameter cylinders closed manually at about 5 mm/minute. Usually at least six briquettes that visually appeared the strongest were crushed and the average value reported. Extreme individual test values were occasionally discarded before averaging. The load at which a briquette first cracks has been previously reported to be useful and meaningful for comparison purposes, and this was used as the crushing strength in this study[20].

Statistical Analysis

Statistical regression analyses were used to attempt to find mathematical relationships between the influence of several experimental variables and briquette crushing strength, and to compare the crushing strength trends of the green, oxidized and heat-treated briquettes. A Hewlett-Packard 9810A calculator was used to carry out standard least-squares regression analyses for linear ($Y = A + BX$), parabolic ($Y = A + BX + CX^2$), exponential ($Y = AC^{BX}$), power ($Y = AX^B$) and semilog ($Y = A + B\ln X$) models[21,22]. Details of the analyses appear in Appendix A.

RESULTS AND DISCUSSION

Various factors such as material size and type, amount and quality of binder and the conditions of production have been shown to influence the strength of briquettes made with coal and/or coal-char using pitch as a binder[23]. This section will discuss the results of a preliminary investigation of the influence that size consist, volatile matter and asphalt (pitch) content had on the crushing strengths of green, oxidized and heat-treated briquettes. A summation of the briquette composition and results appears in Table 3.

The effects of percentage asphalt content and size consist on the three types of briquettes are seen in Figures 2 to 4. The green briquette crushing strengths, with the data from all the briquetted material size consists included, was related to the percentage asphalt content as seen in Figure 2 and could be mathematically related using the linear regression equation (see Appendix A, Table 4 for details)

$$Y = -116.10 + 33.54\ X$$

where Y = crushing strength (lb),

X = asphalt content (%).

The linear model was abritrarily chosen, although other models were also acceptable, because of its simplicity. No fundamental relationship that the authors are aware of, exist to assist the authors in choosing the model. The oxidized briquette results seen in Figure 3 appear to indicate a general increase in the crushing strength with an increase in percentage pitch, although the data is somewhat scattered. As well, the results for the two coarser sized Luscar and Forestburg chars had lower crushing strengths than for the finer sized ERCO and Canmore materials. Surprisingly, the results in Figure 4 indicate no clear relationship between heat treated crushing strengths and percentage asphalt, although except for one point, the finer materials were stronger than the briquettes made with the coarser Luscar char. This lack of relationship could be due to poor experimental data and/or the oxidizing and heat-treating method used on these briquettes. A further discussion on these treatment methods will appear later in this section.

The influence of coal and char volatile matter on the crushing strength of the green, oxidized and heat-treated briquettes is seen in Figures 5 to 7. To remove the effect of asphalt content, only the results of briquettes containing about 10 percent asphalt were used in the Figures. The green briquette crushing strengths did not appear to be related to the volatile matter content as seen in Figure 5, and this was supported by statistical analysis (see Appendix A, Table 5 for details). However, the oxidized and heat-treated briquette strengths seen in Figures 6 and 7 could be statistically related to volatile content using the equations (see Appendix A, Tables 6 and 7 for details).

$$Y = 529.64 - 123.25 \ln X \quad (2)$$

and

$$Y_1 = 787.80\, X^{-0.6861} \quad (3)$$

where Y = oxidized crushing strength (lb),

Y_1 = heat treated crushing strength (lb),

X = briquetted material (e.g. coal and/or char) volatile matter (%)

Equation (2) was chosen over a parabolic model since it tended to suggest a fundamental relationship. As the results in Figures 3, 4, 6 and 7 indicated the coarse sized Luscar and Forestburg chars yielded lower strength briquettes, their results were not used in deriving equations (2) and (3). It is interesting to note that briquettes made with material having a low volatile content tend to yield significantly stronger oxidized or heat-treated briquettes.

Comparisons were made between green, oxidized and heat-treated briquette strengths to determine if interdependency existed. This might be expected since common factors may influence the strength of all the briquette types. No relationships were evident between green and oxidized or heat-treated briquettes (see Figures 8 and 9) and this was supported by statistical analysis. However, there appeared to be a trend between the oxidized and heat-treated results seen in Figure 10 that could be statistically related by the equation (see Appendix A, Table 10 for details).

$$Y = 0.2060\ X^{1.2263}$$

where Y = heat-treated crushing strength (lb), (4)
X = oxidized crushing strength (lb).

This model was chosen since it had the highest correlation coefficient of all the models regressed.

The oxidation method used in this study, mainly 2 hours in air at 240°C, was based on the results of previous work[24] and was chosen because of its simplicity and speed. Oxidation was necessary to prevent the briquette from falling apart during heat-treating to semi-coke. However, the difficulties in interpreting the oxidation results seen in Figure 3 resulted in a cursory study being carried out on the relationship between briquette oxidation time and strength. The results that appear in Figures 11 and 12 for briquettes from test numbers 7, 8, 9 and 10, indicate that the oxidation conditions should be given closer attention in the future. The observed drop in strength in the first hour or so of oxidation might be the result of the briquettes being exposed to air for a year before oxidation. Room temperature air oxidation of the asphalt binder would be expected and this was observed in a significant increase in the strength of the green briquettes. Upon heating, the partially oxidized (weathered) asphalt then softened during the first hour to yield a weaker briquette that subsequently devolatolized and further oxidized with the expected exponential increase in briquette strength[24].

The heat-treating method (mainly 1 hour at 550°C) was chosen because 550°C was found to be a good condition to semi-coke hot briquettes. The results in Figure 4 suggest that the coking method used for the pitch-bound briquette curing also needs further study.

CONCLUSIONS

1) The percentage binder content and material size consist were shown to influence the crushing strength of green oxidized and heat-treated briquettes made with coal and/or coal-char using asphalt as a binder. Increased pitch binder content in green or oxidized briquettes increased the briquette strength, but no relationship was evident for the heat-treated ones. Although no differences were noted with green briquettes, it was also observed that the oxidized and heat-treated briquettes made with the coarser materials were weaker than these made with the finer materials.

2) Coal and char volatile matter had no influence on the the crushing strength of green briquettes but did in the case of the oxidized or heat-treated samples. Generally briquettes with the lower coal or char volatile contents (e.g. less than 7%) yielded a much stronger final product when oxidized or heat-treated according to the conditions used in this report. That is 2 hours air oxidation at 240°C in a muffle furnace and then heat-treating for one hour at 550°C in a nitrogen purged intermittently fluidized sand bed.

3) A relationship was found between the crushing strength of the oxidized and heat-treated briquettes, but none was found for the green briquettes.

4) The method of oxidiation used in this study was shown not to be the best method although it was based on previous work. Future studies need to consider the oxidization step in some detail and how it influences the strength of briquettes obtained from the final heat-treating.

5) The method of heat-treating used in this study was based on previous conditions used to carbonize briquettes containing a coal binder. Further efforts are needed to optimize this step in future studies with pitch-bound briquettes.

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TABLE 1

CHEMICAL AND THERMAL RHEOLOGICAL ANALYSES OF COALS

		Sysco hvb Blend	Fording mvb	McIntyre Porcupine lvb	Canmore Semi Anthracite	Forestburg Sub-bituminous	Luscar Lignite
Proximate Analysis (dry basis)							
Ash	%	6.1	9.7	7.2	6.7	6.0	13.5
Volatile Matter	%	35.6	22.0	18.3	13.8	42.0	40.0
Fixed Carbon	%	58.3	68.3	74.5	79.5	52.0	46.5
Ultimate Analysis (dry basis)							
Carbon	%	80.6	80.9	84.6	-	-	-
Hydrogen	%	5.4	4.7	4.5	-	-	-
Sulphur	%	1.65	0.48	0.36	0.77	0.54	0.58
Nitrogen	%	1.80	1.3	1.3	-	-	-
Ash	%	6.1	9.7	7.2	-	-	-
Oxygen (by difference)	%	4.4	2.9	2.0	-	-	-
Gieseler Plasticity							
Max. Fluidity	dd/min*	25,100	2.4	1.1	-	-	-
Ruhr Dilatation							
Contraction	%	28	27	22	-	-	-
Dilatation	%	240	-26	nil at 500°C	-	-	-
Free Swelling Index (F.S.I.)		7½	5	6			

*dd/min - dial divisions per minute

TABLE 2

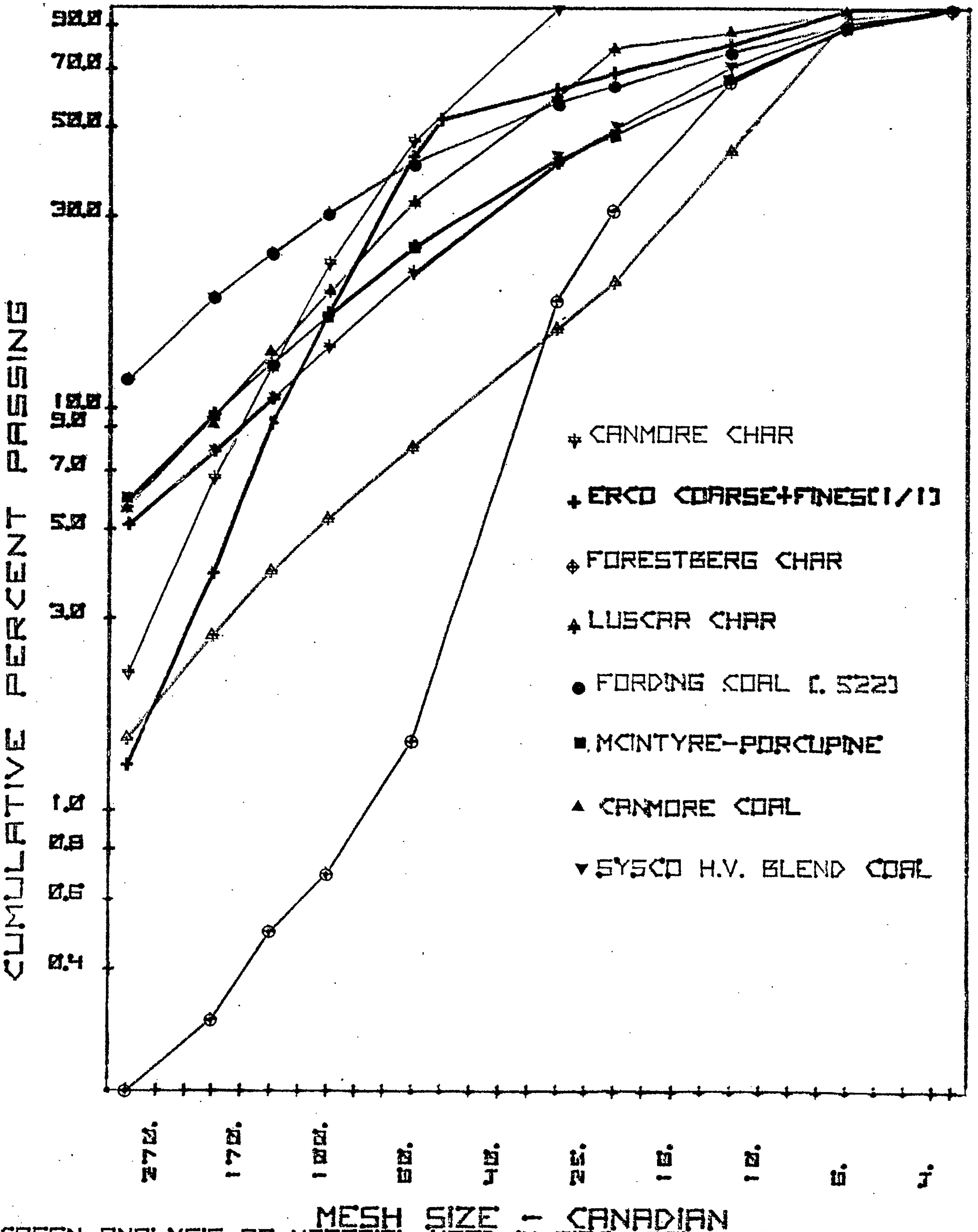
Proximate and Sulphur Analyses of Coal Chars and Coke Fines

		Luscar Commercial Lignite Char	Forestburg Sub-bituminous Char	Canmore Semi-anthracite Char	ERCO Metallurgical Coke Fines
Proximate Analysis (dry basis)					
Ash	%	10.8	11.5	10.65	12.5
Volatile Matter	%	12.9	9.4	4.45	3.5
Fixed Carbon	%	75.6	79.1	84.9	83.7
Ultimate Analysis (dry basis)					
Sulphur	%	0.5	0.55	0.56	0.74

TABLE 3

Summary of Briquette Composition and Crushing Strength Results

Test No.	Briquetted Materials (% By Weight of Total Mixture Briquetted)	Pitch Content (% by wt.)	Crushing Strength (lb)			Coal or Char Volatile Matter %
			Green	Oxidized	Heat-Treated	
1	Erco Metallurgical Coke Fines	9.1	233	325	326	3.0
2		4.75	85.2	276.5	264	-
3		13.0	328.3	407.5	235	-
4	Canmore Semi-anthracite Char	8.8	123	293	240	4.45
5		11.1	254	440	427	4.45
6		7.5	116.7	232	565	-
7		14.0	383.3	347	434	-
8	Forestburg Sub-bituminous Char	11.2	285	67.5	-	5.0
9		8.5	110	135	-	5.0
10		5.4	128	135	-	-
11	Luscar Lignite Char	9.8	175	83.3	36.7	12.0
12		13.5	387	302	75	-
13		7.6	120	96	20	-
14	Sysco High Volatile Coking Coal Blend	10.0	248	116.7	55	35.6
15	Fording Medium Volatile Bituminous Coal	10.0	232	95	92.5	22.0
16	McIntyre-Porcupine Low Volatile Bituminous Coal	10.1	227	118	97	18.3
17	McIntyre-Porcupine Coal-25% + Canmore Coal-65%	10.2	220	116	92	16.71
18	Fording Coal-25% + Canmore Coal-65%	9.5	245	213	147	17.74
19	Sysco H.V. Blend Coal-15% + Canmore Coal-75%	10.7	247	132	113	19.35
20	McIntyre-Porcupine Coal-25% + Canmore Char-65%	10.0	185	310	110	8.3
21	Sysco H.V. Blend Coal-15% + Canmore Char-75%	10.0	167	314	207	9.64
22	Fording Coal-65% + Canmore Char-25%	10.5	165	243	158	17.13



SCREEN ANALYSIS OF MATERIAL USED IN PITCH BOUND BRIQUETTES

FIGURE 1

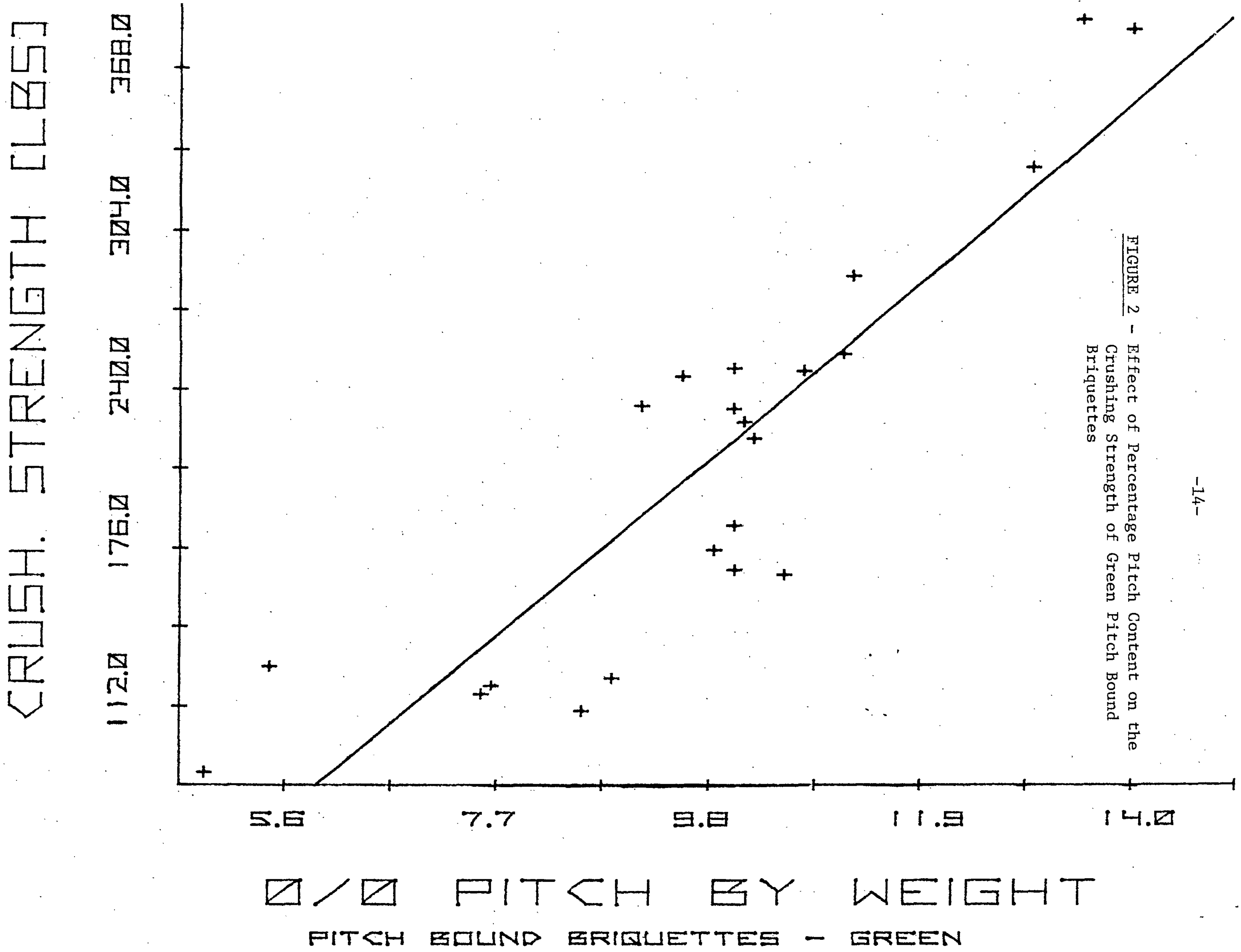


FIGURE 2 - Effect of Percentage Pitch Content on the Crushing Strength of Green Pitch Bound Briquettes

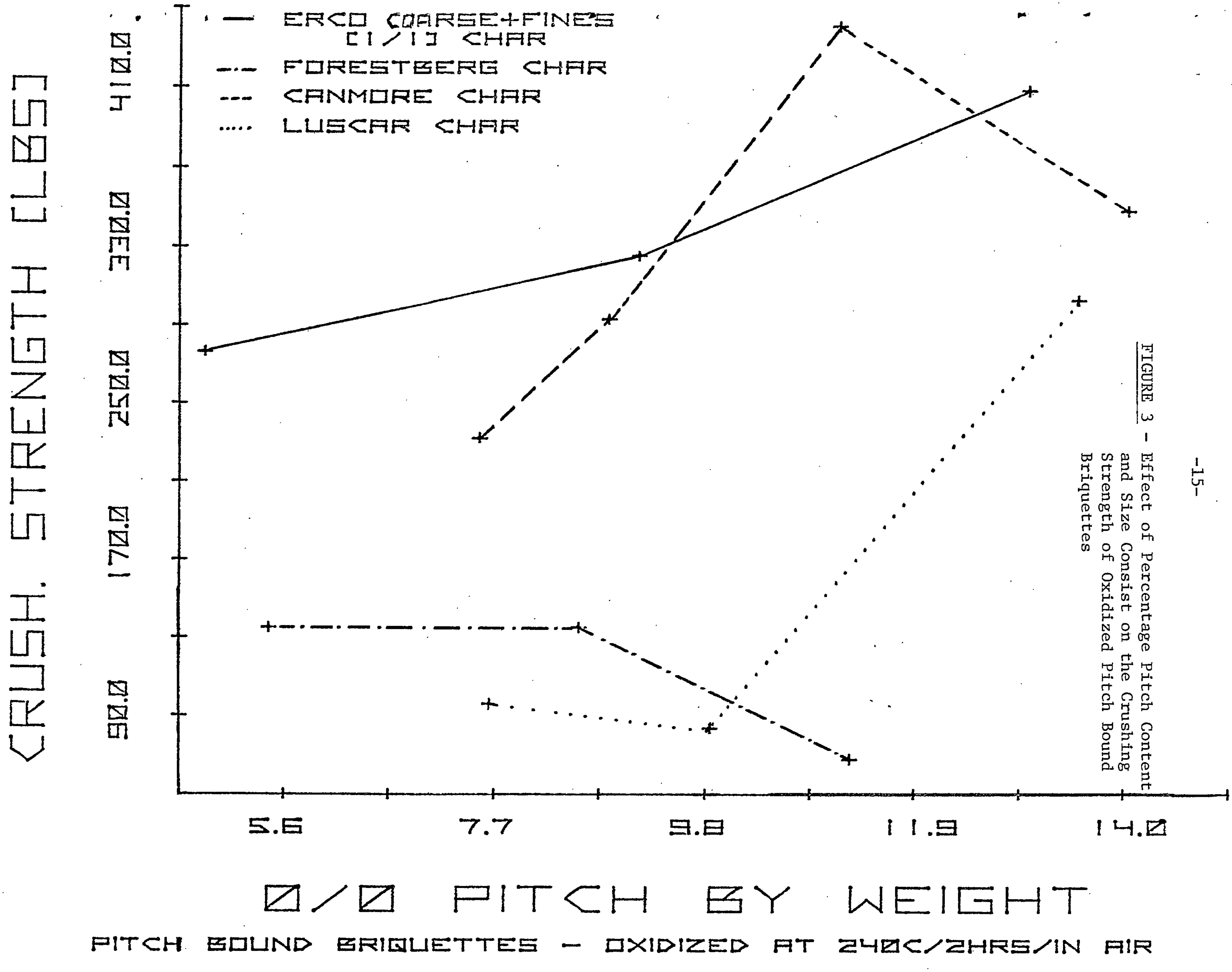


FIGURE 3 - Effect of Percentage Pitch Content and Size Consist on the Crushing Strength of Oxidized Pitch Bound Briquettes

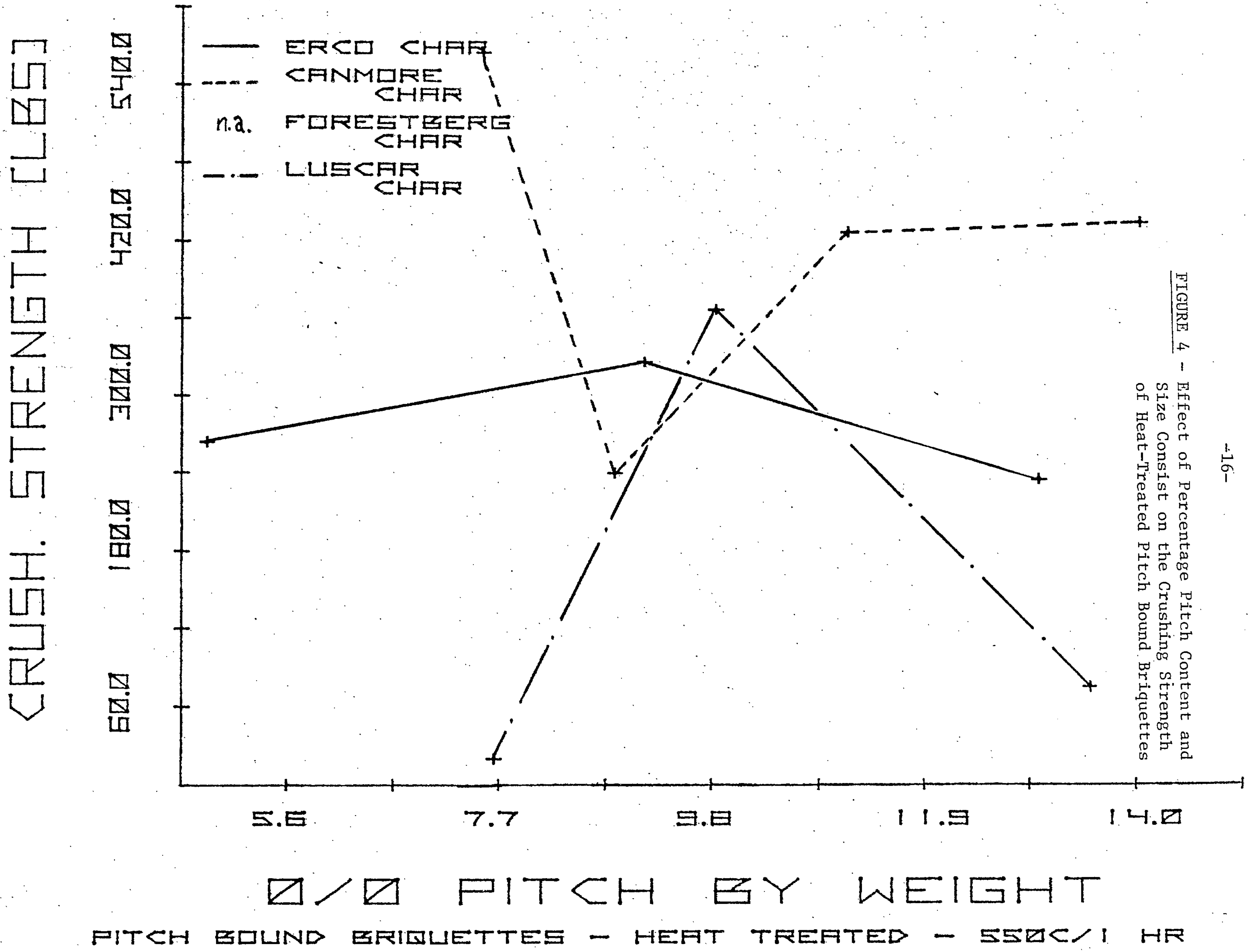


FIGURE 4 - Effect of Percentage Pitch Content and Size Consist on the Crushing Strength of Heat-Treated Pitch Bound Briquettes

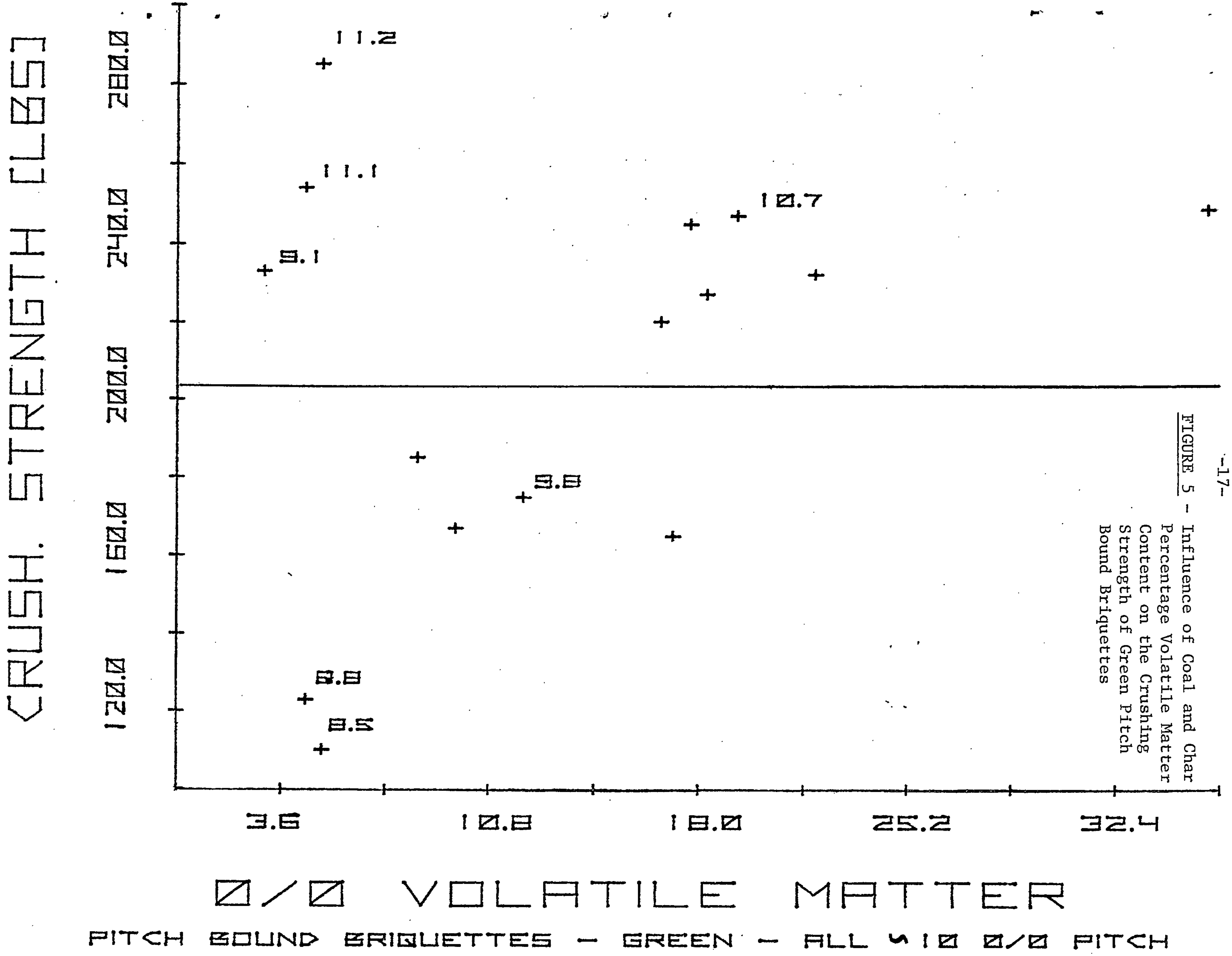


FIGURE 5 - Influence of Coal and Char Percentage Volatile Matter Content on the Crushing Strength of Green Pitch Bound Briquettes

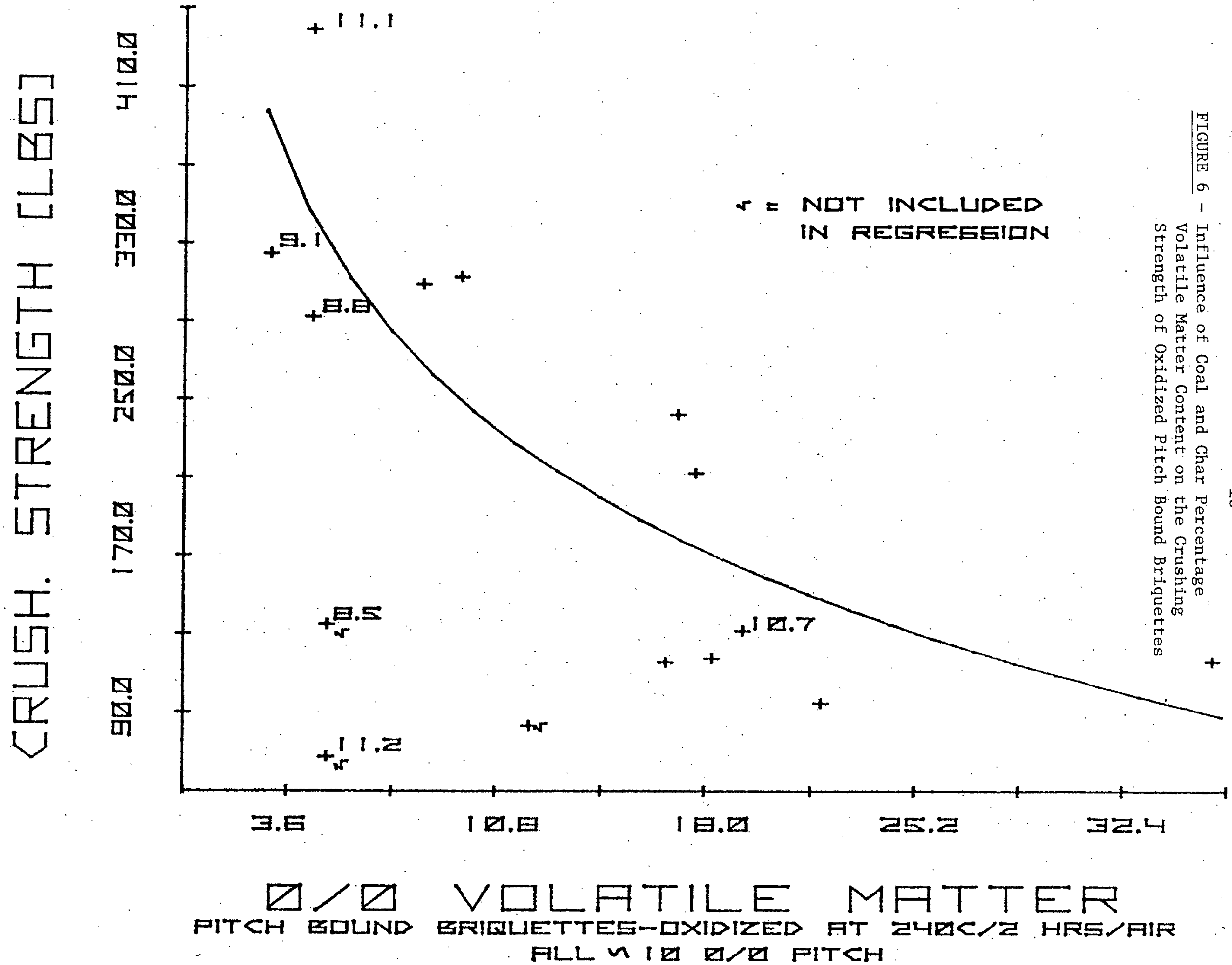


FIGURE 6 - Influence of Coal and Char Percentage Volatile Matter Content on the Crushing Strength of Oxidized Pitch Bound Briquettes

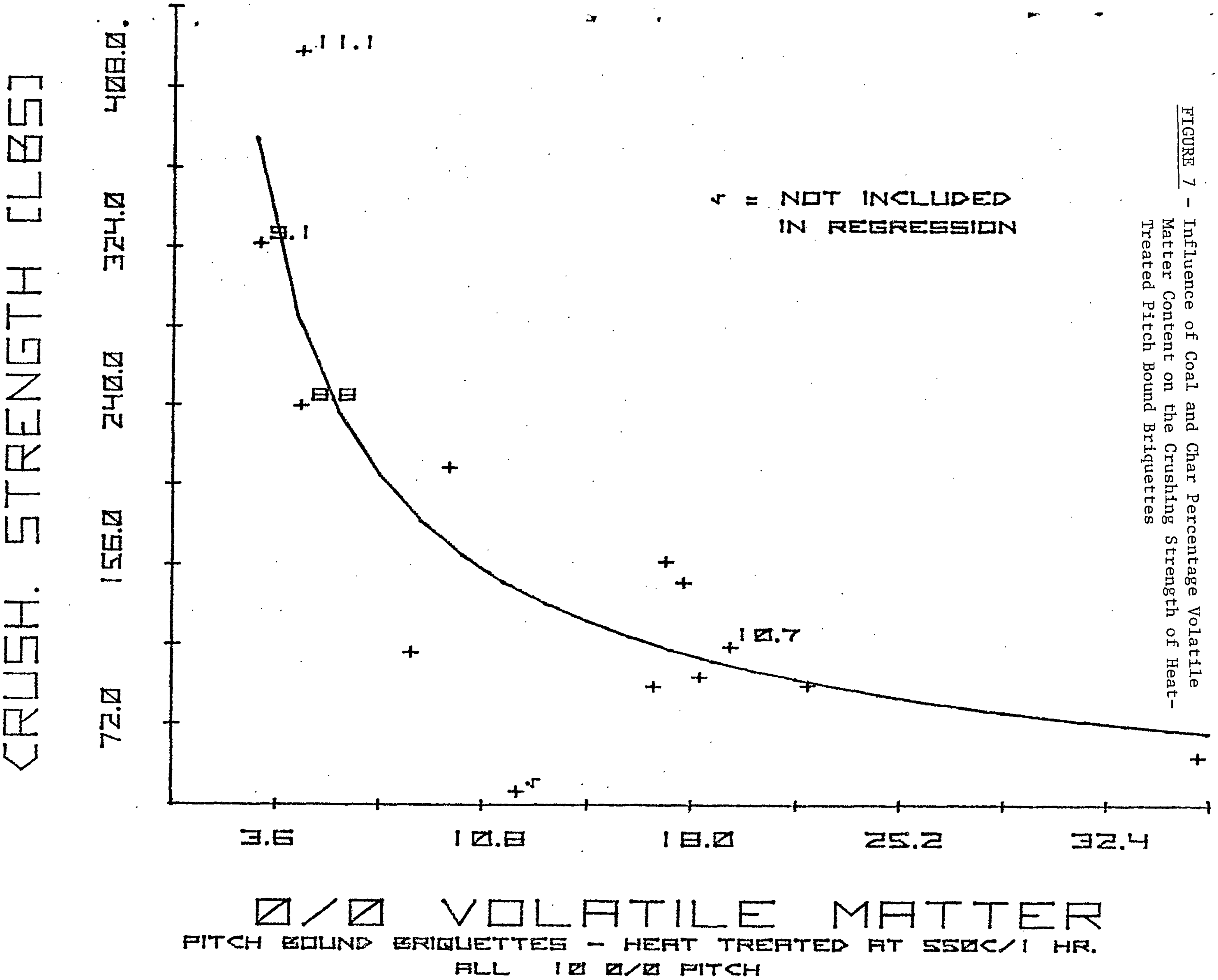


FIGURE 7 - Influence of Coal and Char Percentage Volatile Matter Content on the Crushing Strength of Heat-Treated Pitch Bound Briquettes

FIGURE 8 - Comparison of Green and Oxidized Pitch Bound Briquette Crushing Strengths

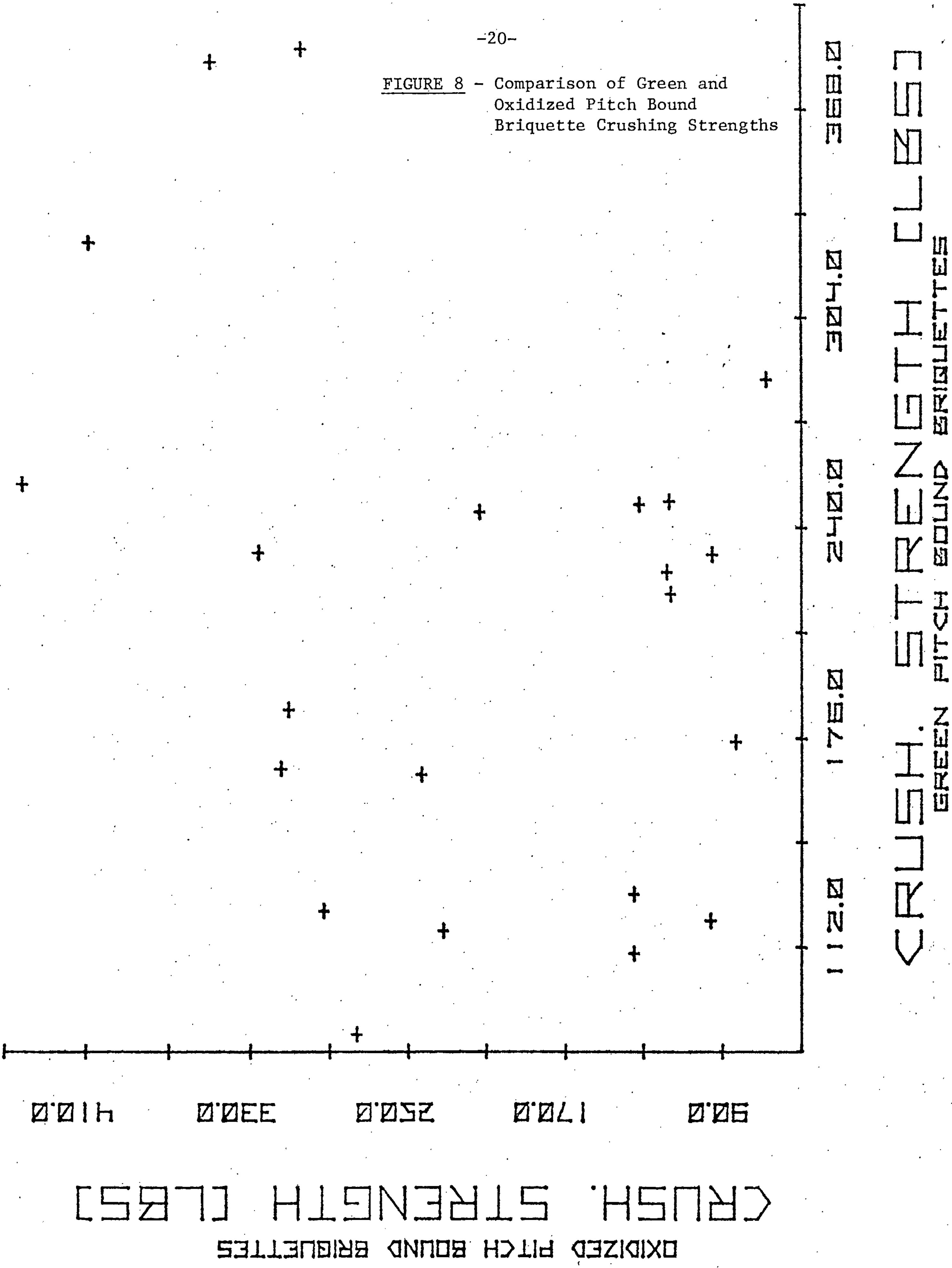
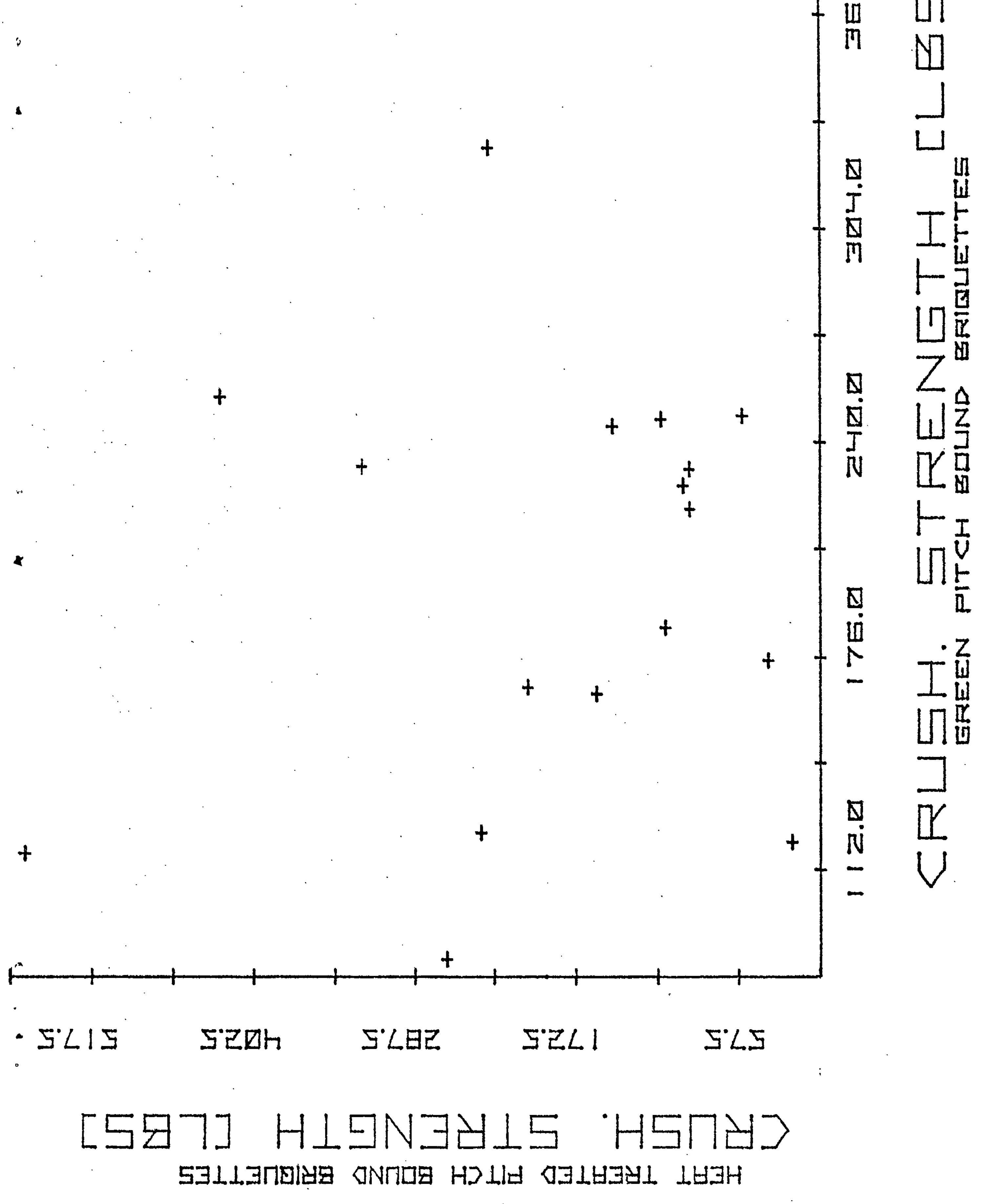


FIGURE 9 - Comparison of Green and Heat-Treated Pitch Bound Briquette Crushing Strengths



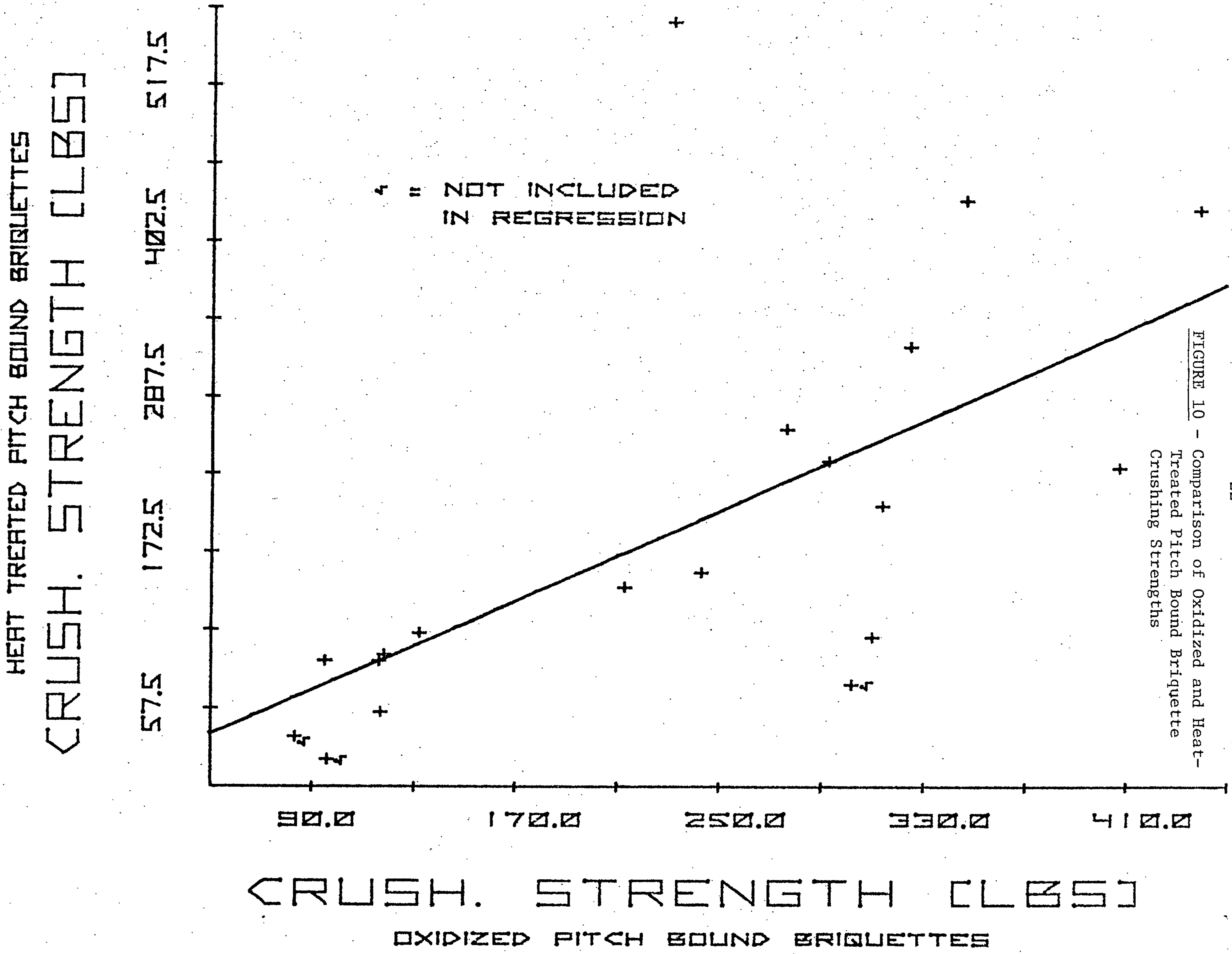
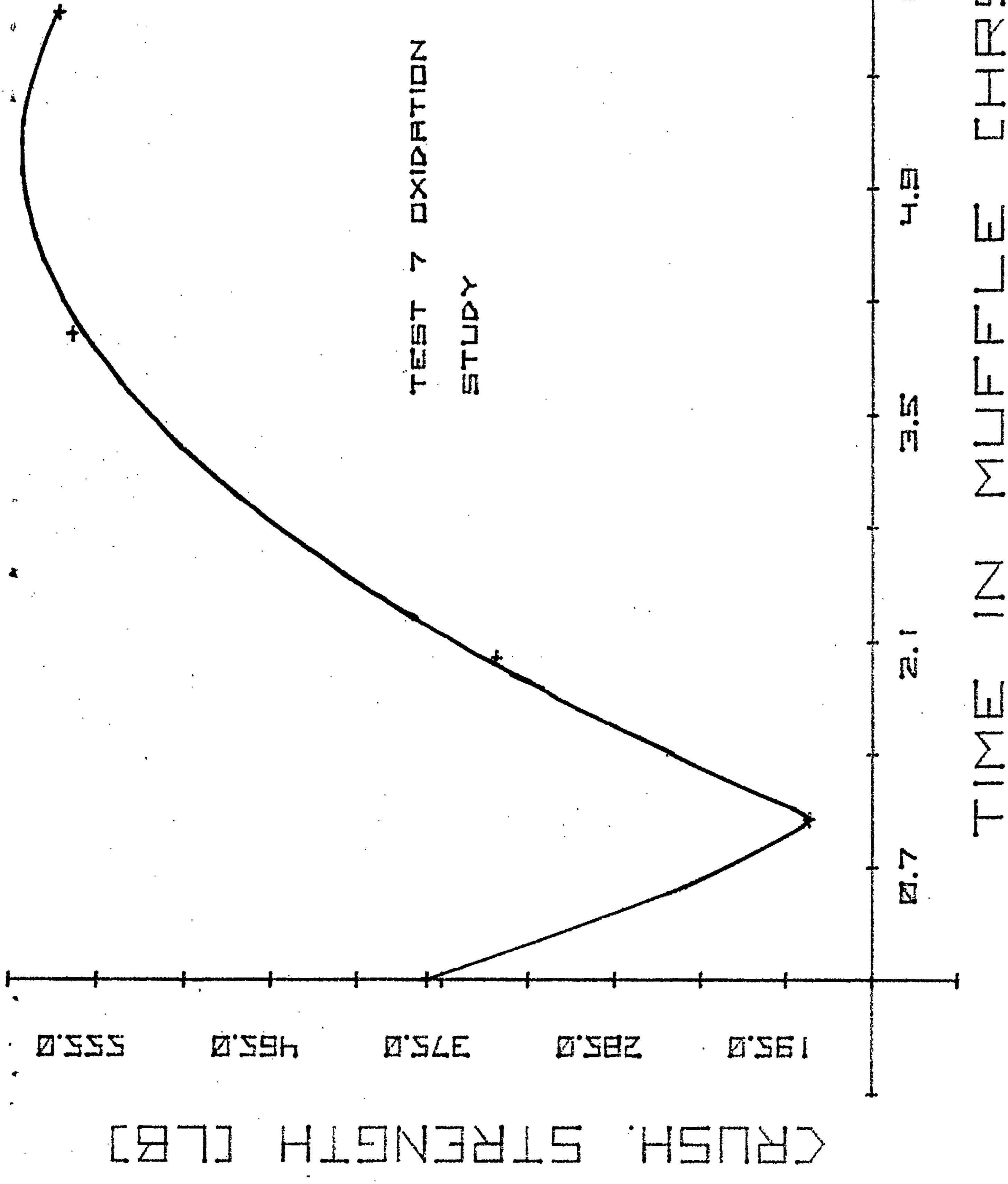


FIGURE 10 - Comparison of Oxidized and Heat-Treated Pitch Bound Briquette Crushing Strengths

FIGURE 11 - Effect of Oxidation Time on Test 7 Pitch Bound Briquette Crushing Strength



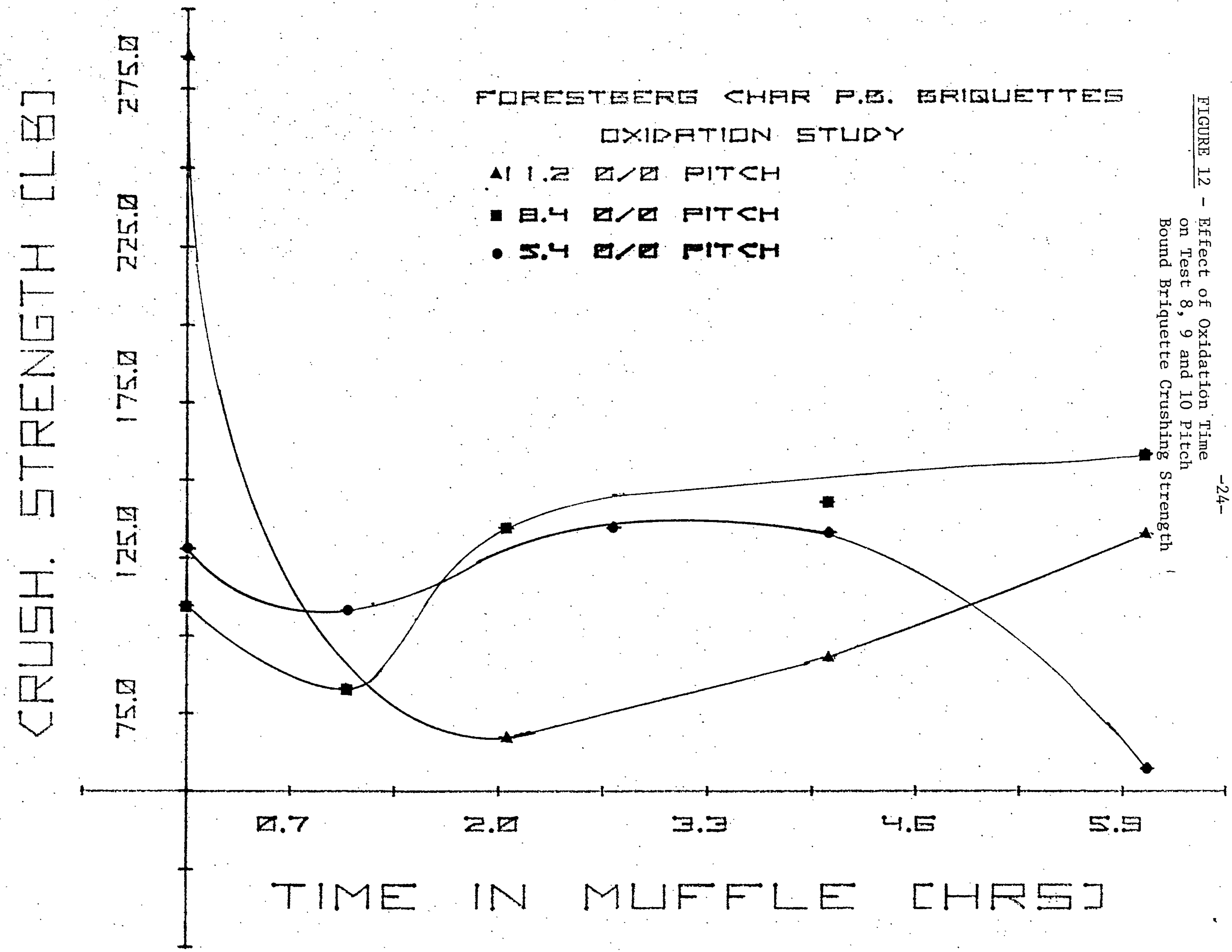


FIGURE 12 - Effect of Oxidation Time on Test 8, 9 and 10 Pitch Bound Briquette Crushing Strength

APPENDIX A

The Results of the Hewlett-Packard 9810A
Calculator Statistical Analysis Calculations
on Pitch Bound Briquette Crushing
Strength Data

The definitions of the symbols used in the tables are: mean of X ($\bar{X}$); standard deviation of X (S_x); mean of Y ($\bar{Y}$); standard deviation of Y (S_y); regression sum of squares of deviation (REG. S.S.); residual sum of squares is the sum of squares of deviations and will be called sum of squares henceforth (RES. S.S.); total sum of squares (Total S.S.); regression mean sum of squares (REG. M.S.); residual mean sum of squares (RES. M.S.); upper confidence limit (UCL); lower confidence limit (LCL); standard error (STD. ERR.); and correlation coefficient (R). The constant A and B (and perhaps C) associated with the regression models are defined in the Tables for the particular form of the equation analyzed.

The mathematical definition of R, the correlation coefficient, varies with the mathematical model being considered and a standard statistical text is suggested as a source of reference if further information is desired[21,22]. Generally the models with the highest correlation coefficient or F values were chosen to represent a relationship. In tests to demonstrate a significant relationship t and F-tests were utilized. A model relationship was generally considered significant if its calculated F-ratio was at least four times the F-table value. If a linear relationship had a slope approaching "zero", a statistical test using a "null hypothesis" was employed to determine if a slope of zero for the line was possible (could not be rejected). That is, statistically speaking there is "no significant difference" between the linear regression slope and the hypothetical slope of zero. If it was found that a slope of zero did not result in $|\text{t-test}| \geq |\text{t-table}|$, the null hypothesis was not rejected and it was concluded that the best estimate of Y was its average value ($\bar{Y}$).

TABLE 4 - Statistical Analysis (using Hewlett-Packard 9810A Calculator) of Crushing Strength vs % Pitch by weight of Green Pitch Bound Briquettes (see Figure 2 for graphical presentation)

Y=Crushing Strength (lbs)   X=% Pitch by Weight

Data		Regression Curve	Analysis of Variance Table
X	Y		
9.1	233.0	**Linear**	
4.75	85.2	Y = A+BX	$\bar{X}$ = 9.78
13.0	328.3	A = -116.10	S_x = 2.24
8.8	123.0	B = 33.54	$\bar{Y}$ = 212.01
11.1	254.0	R^2 = 0.7852	S_y = 84.70
7.5	116.7	**Parabolic**	**Linear**
14.0	383.3	$Y = A+BX+CX^2$	REG. S.S. = 118294.13
11.2	285.0	A = 127.96	RES. S.S. = 32361.67
8.5	110.0	B = -21.16	Total S.S. = 150655.80
5.4	128.0	C = 2.90	
9.8	175.0		REG. M.S. = 118294.13
13.5	387.0	R^2 = 0.8484	RES. M.S. = 1618.08
7.6	120.0	**Exponential**	
10.0	248.0	$Y = Ae^{BX}$	F-Ratio = 73.1
10.0	232.0	A = 38.65	Std. Err. = 40.23
10.1	226.7	B = 0.1658	F-Table Value @ 95% = 4.35 (approx)
10.2	220.0	R^2 = 0.7936	
9.5	245.0	**Power**	
10.7	247.0	$Y = AX^B$	UCL for B = 41.72
10.0	185.0	A = 8.527	LCL for B = 25.35
10.0	167.0	B = 1.391	Where t Value = 2.09
10.5	165.0	R^2 = 0.7403	

TABLE 5 - Statistical Analysis (using Hewlett-Packard 9810A Calculator) of Crushing Strength vs % Total Volatile Matter of Green Pitch Bound Briquettes (see Figure 5 for graphical presentation)

Y = Crushing Strength (lbs) X = % Volatile Matter

Data		Regression Curve	Analysis of Variance Table
X	Y		
3.0	233.0	Linear	
4.45	254.0	$Y = A+BX$	$\bar{X}$ = 13.24
4.45	123.0	A = 183.6108	S_x = 8.949
5.0	285.0	B = 1.821	$\bar{Y}$ = 207.73
5.0	110.0	R^2 = 0.1027	S_y = 50.86
12.0	175.0	Parabolic	Linear
35.6	248.0	$Y = A+BX+CX^2$	REG. S.S = 3718.79
22.0	232.0	A = 191.64	RES. S.S. = 32498.15
18.3	227.0	B = 0.4682	Total S.S.= 36216.94
16.71	220.0	C = 0.0395	REG. M.S. = 3718.79
17.74	245.0	R^2 = 0.1088	RES. M.S. = 2499.86
19.35	247.0	Exponential	
8.3	185.0	$Y = Ae^{BX}$	F-Ratio = 1.49
9.64	167.0	A = 173.74	Std. Err. = 50.00
17.13	165.0	B = 0.0110	F-Table Value @ 95% = 4.67
		R^2 = 0.1270	
		Power	
		$Y = AX^B$	UCL for B = 5.05
		A = 155.17	LCL for B = -1.40
		B = 0.1102	Where t Value = 2.16
		R^2 = 0.0870	

TABLE 6 - Statistical Analysis (using Hewlett-Packard 9810A Calculator) of Crushing Strength vs % Total Volatile Matter of Oxidized Pitch Bound Briquettes (see Figure 6 for graphical presentation)

Y = Crushing Strength (lbs) X = % Volatile Matter

Data		Regression Curve	Analysis of Variance Table
X	Y		
3.0	325.0	**Linear**	
4.45	293.0	Y = A+BX	$\bar{X}$ = 14.72
4.45	440.0	A = 369.43	S_x = 9.32
35.6	116.7	B = -9.72	$\bar{Y}$ = 226.31
22.0	95.0	R^2 = 0.6602	S_y = 111.62
18.3	118.0	**Parabolic**	**Semi Log**
16.71	116.0	$Y = A+BX+CX^2$	REG. S.S. = 97412.62
17.74	213.0	A = 444.62	RES. S.S. = 39637.73
19.35	132.0	B = -21.66	Total S.S. =137050.35
8.3	310.0	C = 0.3393	REG. M.S. = 97412.62
9.64	314.0	R^2 = 0.7686	RES. M.S. = 3963.77
17.13	243.0	**Exponential**	
		$Y = Ae^{BX}$	F-Ratio = 24.58
		A = 392.78	Std. Err. = 62.96
		B = -0.0457	F-Table Value @ 95% = 4.96
		R^2 = 0.6583	
		Power	
		$Y = AX^B$	UCL for B = -120.99
		A = 810.224	LCL for B = -125.52
		B = -0.5674	Where t Value = 2.228
		R^2 = 0.6807	
			Semi Log
			Y = A+B (LnX)
			A = 529.64
			B =-123.25
			R^2 = 0.7108

TABLE 7 - Statistical Analysis (using Hewlett-Packard 9810A Calculator) of Crushing Strength vs % Total Volatile Matter of Heat Treated Pitch Bound Briquettes (see Figure 7 for graphical presentation)

Y = Crushing Strength (lbs) X = % Volatile Matter

Data	
X	Y
3.0	326.0
4.45	240.0
4.45	427.0
35.6	55.0
22.0	92.5
18.3	97.0
16.71	92.0
17.74	147.0
19.35	113.0
8.3	110.0
9.64	207.0
17.13	158.0

Regression Curve	Analysis of Variance Table
Linear	
$Y = A+BX$	$\bar{X} = 14.72$
$A = 306.34$	$S_x = 9.33$
$B = -9.12$	$\bar{Y} = 172.04$
$R^2 = 0.5911$	$S_y = 110.69$
Parabolic	**Power**
$Y = A+BX+CX^2$	REG S.S. = 3.0185
$A = 384.84$	REG S.S. = 0.8413
$B = -21.59$	Total S.S= 3.8598
$C = 0.3543$	REG S.S. = 3.0185
$R^2 = 0.7113$	RES M.S. = 0.0841
	F-Ratio = 35.88
	Std. Err = 0.2900
Exponential	
$Y = Ae^{BX}$	F-Table Value @ 95% = 4.96
$A = 326.68$	UCL for B= -0.6757
$B = -0.0549$	LCL for B= -0.6965
$R^2 = 0.7476$	Where t Value = 2.228
Power	**Semi Log**
$Y = AX^B$	$Y = A+B(\ln X)$
$A = 787.80$	$A = 477.23$
$B = -0.6861$	$B = -124.01$
$R^2 = 0.7820$	$R^2 = 0.7317$

TABLE 8 - Statistical Analysis (using Hewlett-Packard 9810 Calculator) of Oxidized Crushing Strength vs Green Crushing Strength of Pitch Bound Briquettes (see Figure 8 for graphical presentation)

Y = Oxidized Crushing Strength (lbs)
X = Green Crushing Strength (lbs)

Data		Regression Curve	Analysis of Variance Table
X	Y		
233.0	325.0	**Linear**	
123.0	293.0	$Y = A+BX$	$\bar{X} = 212.02$
254.0	440.0	$A = 139.17$	$S_x = 84.70$
285.0	67.5	$B = 0.372$	$\bar{Y} = 218.07$
110.0	135.0	$R^2 = 0.077$	$S_y = 113.51$
175.0	83.3	**Parabolic**	F-Table Value @ 95% = 4.35
248.0	116.7	$Y = A+BX+CX^2$	F-Ratio for Linear Regression = 1.67
232.0	95.0	$A = 317.411$	
227.0	118.0	$B = -1.397$	F-Ratio for Parabolic Regression = 1.68
220.0	116.0	$C = 0.004$	F-Ratio for Exponential Regression = 0.78
245.0	213.0	$R^2 = 0.150$	
247.0	132.0		F-Ratio for Power Regression = 0.31
185.0	310.0	**Exponential**	F-Ratio for Semilog Regression = 0.95
167.0	314.0	$Y = Ae^{BX}$	**Conclusion**
165.0	243.0	$A = 142.890$	No relationship exists between X and Y
85.2	276.5	$B = 0.001$	
328.3	407.5	$R^2 = 0.038$	
116.7	232.0	**Power**	**Semi Log**
383.3	347.0	$Y = AX^B$	$Y = A+B (LnX)$
128.0	135.0	$A = 78.741$	$A = -88.21$
387.0	302.0	$B = 0.170$	$B = 58.04$
120.0	96.0	$R^2 = 0.015$	$R^2 = 0.045$

TABLE 9 - Statistical Analysis (using Hewlett-Packard 9810 Calculator) of Heat Treated Crushing Strengths vs Green Crushing Strength of Pitch Bound Briquettes (see Figure 9 for graphical presentation)

Y = Heat Treated Crushing Strength (lbs), X = Green Crushing Strength (lbs)

Data			
X	Y	Regression Curve	Analysis of Variance Table
233.0	326.0	**Linear**	
85.2	264.0	Y = A+BX	$\bar{X}$ = 217.97
328.3	235.0	A = 193.15	S_x = 84.06
123.0	240.0	B = 0.0059	$\bar{Y}$ = 194.43
254.0	427.0	R^2 = 0.0000	S_y = 151.21
116.7	565.0	**Parabolic**	F-Table Value @ 95% = 4.45
383.3	434.0	$Y = A+BX+CX^2$	F-Ratio for Linear Regression = 0.0002
175.0	36.7	A = 470.00	
387.0	75.0	B = - 2.65	F-Ratio for Parabolic Regression = 0.8334
120.0	20.0	C = 0.0056	F-Ratio for Exponential Regression = 0.1012
248.0	55.0	R^2 = 0.0943	
232.0	92.5		F-Ratio for Power Regression = 0.0073
227.0	97.0	**Exponential**	F-Ratio for Semi-Log Regression = 0.0915
220.0	92.0	$Y = Ae^{BX}$	**Conclusion**
245.0	147.0	A = 119.09	No relationship exists between X and Y
247.0	113.0	B = 0.0008	
185.0	110.0	R^2 = 0.0059	
167.0	207.0	**Power**	**Semi Log**
165.0	158.0	$Y = AX^B$	Y = A+B (LnX)
		A = 111.95	A = 339.05
		B = 0.0445	B = -27.24
		R^2 = 0.0004	R^2 = 0.0054

TABLE 10 - Statistical Analysis (using Hewlett-Packard 9810 Calculator) of Heat Treated Crushing Strength vs Oxidized Crushing Strength of Pitch Bound Briquettes (see Figure 10 for graphical presentation)

Y = Heat Treated Crushing Strength (lbs)
X = Oxidized Crushing Strength (lbs)

Data		Regression Curve	Analysis of Variance Table
X	Y		
325	326	**Linear**	
276.5	264	Y = A+BX	$\bar{X}$ = 234.74
407.5	235	A = -6.740	S_x = 121.75
293	240	B = 0.857	$\bar{Y}$ = 194.43
440	427	R^2 = 0.4083	S_y = 151.21
232	565	**Parabolic**	**Power**
347	434	$Y = A+BX+CX^2$	REG S.S. = 3.9521
83.3	36.7	A = -55.65	RES S.S. = 2.7478
302	75	B = 1.371	Total S.S. = 6.6999
96	20	C = - 0.0011	REG M.S. = 3.9521
116.7	55	R^2 = 0.4144	RES M.S. = 0.1963
95	92.5		
118	97	**Exponential**	
116	92	$Y = Ae^{BX}$	F-Ratio = 20.1363
213	147	A = 37.27	Std. Err. = 0.4430
132	113	B = 0.0057	F-Table Value @ 95% = 4.45
310	110	R^2 = 0.5393	
314	207	**Power**	
243	158	$Y = AX^B$	UCL for B = 1.2273
		A = 0.2060	LCL for B = 1.2253
		B = 1.2263	Where t Value = 2.11
		R^2 = 0.5941	