THE EFFECTS OF SOME MANUFACTURING VARIABLES ON THE PROPERTIES OF PARTICLEBOARD

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ABSTRACT

The effects of type of wood furnish particle-board, specific gravity and press closing speed on properties of resultant particleboard were investigated. Tests were done in accordance with the provisions of ASTM D 1037 - 78 and property values compared with minimum values set by Commercial Standard - CS 236 - 66. Property values investigated were *Modulus OJ Rupture (MOR) andModulus Of Elasticity (M.O.E.)* in bending as well as the Internal Bond (IB). Data were analyzed using factorial analysis and regression analysis with Dummy Variables. Most variables and/or their interaction were found to have significantly (at 0.01 level) affected properties. Using compression ratio (ratio of particleboard specific gravity/furnish specific gravity), it was possible to arrive at equations, which gave predicted best estimates of M.O.R; M.O.E. and lB. Similarly, regression equations of compression ratio on M.O.R, M.O.E. and 1B show r = 0.790, r = 0.761 and r = - 0.263 respectively for boards made by fast closing speed while r = 0.601, r = 0.584 and r = -0.450 for slow closing speed, respectively. A student t- test between means of predicted values and experimental results were not significantly different (at 0.05 level) except for all maple board at 0.6 sp. gravity and 3-layer board at 0.7 sp. gravity both of which were made by slow press closing speed. All boards satisfied the provisions set in CS 236 - 66 except boards manufactured from Hard Maple shavings and exposed to the slow press closing speed treatment.

INTRODUCTION

Over 90 per cent of the dry weight of particleboards is composed of wood or other lignocellulosic raw materials. Kelly [1] reported that high quality particleboard could only be made from particles of species of adequate inherent strength that could be broken and reconstituted without unduly destroying the native strength. The most important furnish variable controlling the property of particleboard is the specie's specific gravity [**2-7**]. As a general rule, the density of wood used as furnish should be less than that of the resultant particleboard in order to economically produce high quality board [**2 - 7, 8 - 13].** This is because a lower density wood will require more volume of particles while a higher species density for a given board density reduces the bulk mass of particles and the number of inter-particle contact which are required to achieve effective inter-particle bonding [**14**]. Greater particle contact promotes resin efficiency [**10**].

The cure rate of synthetic binders depends on the pH of the substrate/medium. The effects of pH can however be controlled by the use of catalyst [1,6,9,15] each reported that in mixture of species acidity could become a greater problem since the species buffering capacity may be insufficient for some particles and thus result in premature curing. The use of mixed species is a common practice in the industry [**2, 5, 9, 16**]. The properties of mixed species are comparable to those of single species [16,17] and are generally dependent on the weighted average density of the mixture [**5, 6, 9, 10, 18**] noted that the product technologist has five different techniques to manipulate the particleboard density profile and thus obtain boards tailored to specific end use requirements. The use of layering techniques to enhance properties of boards is fairly established [6,19-24].

An increase in board specific gravity can be achieved by either increasing the weight of the mat or by compressing the mat to a higher degree or both. Higher compression leads to greater contact between particles and thus a more efficient adhesive utilization [5, 11]. However, increase in board specific gravity is not without its adverse effects as this will lead to increase in board swelling [5, 12, 14, 25-28] noted that increase in board density is the most significant factor in reducing Equilibrium Moisture Content (EMC). The predominant resin used in particleboard industry is urea or phenol formaldehyde. Investigators are unanimous in concluding that as the adhesive level increases all strength properties increase [12, 19, 27, 30-35].

The rate of press closing is a function of the initial pressure. High initial pressure will result in short press closing time and vice- versa [36]. Longer press closing time will result in higher degree of wood plasticity and consequently a lower pressure needed to compress the board to stops [37]. The effect of press closing speed is to create specific gravity profile across the board thickness [22, 23, 15] reported that as press closing time is increased, the resultant core density will increase and so does internal bond but bending strength is adversely affected.

AIMS AND OBJECTIVES

From the above discussions the aims and objectives of this study are:

(a) to manufacture flat pressed medium density Urea formaldehyde bonded
particleboard in the laboratory using different selected production variables;

(b) to evaluate the properties of the different boards made by testing for the Modulus of Rupture (M.O.R.) and Modulus of Elasticity (M.O.E.) in bending and the Internal Bond (IB) properties;

(c) to evaluate the effects of the manufacturing variables on resultant board properties; and

d) to determine whether the boards satisfy the requirements of Commercial Standards CS 236-66 or not.

MATERIALS AND METHODS

(a) *Materials*

Logs of Hard Maple (Acer Saccharum Marsh - Oven dry specific gravity 0.67), and White Pine (pinus strobes L. Oven dry specific gravity 0.36) were each received from the State University of New York, College of Environmental Sciences and Forestry, Forest Station. Logs were reduced to cants while still green and subsequently reduced to planer shavings in a light surface planer. Chips were reduced to 3 per cent moisture content in the open laboratory with the help of low winter temperature (-7.5°C) and the fact that the room was heated and had forced ventilation; this was achieved in ten days. At the end, Chips were bagged in plastic bags and left for one month in order to achieve moisture content uniformity. Only particles retained on a 4-mesh screen were used.

Urea formaldehyde (U.F.) used as binder was of the liquid type and had 65 per cent solid content. Seven (7) per cent of U.F. was used as binder based on Oven-dry weight of Chips and U.F. solid content. A preliminary blending in a rotating drum, using particles which had been stained with a red dye (Dupont's Wood Stain Scarlet, NS), helped to select finest adhesive spray pattern that gave the greatest adhesive distribution.

(b) Board Production

The board dimensions were designed to be 1.27cm by 30.48cm by 45.72cm (0.5 inch by 12 inches by 18 inches respectively). Boards were made either of all white pine furnish, all

Hard Maple furnish, homogeneous random mixture of 40 per cent Hard Maple and 60 per cent white pine (wt/wt basis) or 3 - layer board in which 50 per cent by weight of the Hard Maple was used in constructing the face while 50 per cent by wt of the white pine was used for the core. The mats were in all cases hand formed and in the case of the 3-layer boards, the furnish for the face and core were blended separately. Formed mats were later prepressed before formed cake with the supporting thin aluminum bottom platen, was placed in the press. Prior to that, the top platen was sprayed with oil to prevent the board from sticking to it. The formed previously prepressed mat was pressed in an electrically heated platen equipped with hydraulically driven piston to 12.1mm (0.5 inch) stops. The pressure used to effect either fast or slow press closing speed were previously determined from preliminary tests. Pressure used for fast closing speed were $4.83N/mm^2$ and $3.79483N/mm^2$ (700 PSI and 550 PSI respectively) for the 0.7 and 0.6 specific gravities respectively while pressures used for the slow closing speed were 3.45 N/mm^2 and $2.7483N/mm^2$ (500 PSI and 400 PSI respectively) for the 0.7 and 0.6 specific gravities respectively. These gave press-closing speed of either 1.5 minutes for the fast closing and 3.0 minutes for the slow closing. Variation in specific gravity was achieved by the use of more materials for each furnish or board type. A constant press temperature of 350^0C ± 2^0C was used for all boards. A total of 32 boards were made *half* of which were either of 0.6 or 0.7 specific gravity and either made by fast or slow closing speed respectively.

(c) Board Testing

As is stipulated by Commercial Standards CS 236-66 [38], a table of random numbers was used to determine the location of either the bending strength specimens or the internal bond specimens. Specimen sampling and testing were done in accordance with ASTM D1037 - - 78 [39]. Specimens were previously conditioned in Arninco-Aire humidity - temperature controlled chamber before testing.

(d) Statistical Analysis

Data collected were analyzed using factorial analysis and simple linear regression with dummy variables while the means of experimental results were tested for any significant difference from predicated best estimate of properties using a tukey studentized test

RESULTS AND DISCUSSION

The mean property values for all manufacturing conditions are presented in Table 1. Figures 1, 2 and 3 present the effects of manufacturing variables on Modulus of Rupture (M.O.R.); and Modulus of Elasticity (M.O.E.) in bending and Internal Bond (lB) respectively. Table 5 presents the predicated best estimate of M.O.R. and M.O.E. in bending and I.B. using the regression equations relating furnish compression ratio to board properties (also see Figures 4 - 9). The results of the tukey studentized tests to determine whether predicated properties are significantly different from means obtained from the experimental results are shown in Table 5. The results and analysis as they relate to specific mechanical properties are discussed here under:-

(a) Static Bending:

a(i) Modulus of Rupture:- The results showing the effects of studied manufacturing variables are presented in Table 1 and Figure 1, while Table 2 shows the results of the effect due to vanous manufacturing variables on M.O.R. Table 5 presents the predicted best estimate of M.O.R. From Table 2, it will be seen that all the manufacturing variables at main effect level (type of furnish, board specific gravity and press closing speed) as well as the interaction between furnish composition and press closing speed were all found significant at one per cent level while all other interactions were found not to be significant. The implication of this is that the three variables influence board M.O.R. The equation for the best estimate of M.O.R. was found to be thus

$$Y = -2942.264 + 462.369D_1 - 759.063D_2 + 975.860D_3 + 309.774F + 12719.57G + 672.757D_6 + 120.305D_7 - 8659.559D_8$$

where Y = regression estimate of M.O.R.

D_1= 1 if the board type is of pine furnish otherwise zero (0).

D_2 = 1 if the board type is of maple furnish or zero (0) if otherwise.

D_3 =1 if the board type is of random mixture of wood species or zero (0) if otherwise.

F = 1 if board was due to fast closing speed or zero (0) if otherwise.

G = Specific gravity of test specimen.

D_6 = 1 if board type is of pine furnish and press closing speed was fast closing or zero (0) if otherwise.

D_7 = 1 if board type is of maple furnish and press closing speed was fast closing speed was fast or zero (0) if otherwise.

D_8 =1 if board type is of random mixture of species and press closing speed.

A simple regression analysis of board compression ratio on M.O.R. shows a high level of correlation (r = 0.790 or r = 0.601 for boards made by either fast or slow closing speed respectively). The equation relating compression ratio to M. O.R. can be expressed thus (see also figures 4 and 5):-

Y_f = 1421. 7 + 2483 .5x ± 640 and/ or

Y_s = 1614.5 = 2106.4x + 870.

Where Y_f and Y_s are M.O.R. expressed in British units for boards made by either fast or slow closing speed respectively; X = Compression Ratio ±640 and ±877 each represents standard error of estimate or standard deviation of unknown *values* about regression function. Figures 4 and 5 show the effects of Compression Ratio on Modulus of Rupture depending on whether board was manufactured with either fast or slow closing speed.

I. (ii) Modules of Elasticity (M.O.E.):- The results showing the effects of production variables on M.O.E. are presented in Table and Figure 2. The result of factorial analysis showing the effects of the various manufacturing variables involved in this study (furnish composition, board specific gravity and press closing speed) on M.O.E. are presented in Table 3.All the variables and the interaction between the variables as well as their second order interaction were all found to have significant effect (at 0.01 level) on M.O.E. The only exception to this is the board specific gravity whose effect was not found significant but the interaction of board specific gravity with other variables were significant. What this means is that the effect of specific gravity of board M.O.E. will be significant if the manufacturing conditions (furnish composition and press closing speed) were the' same as such factors as the level of inter-particulate contact and board specific gravity profile, etc. might enhance M.O.E. of a board. From the same Table, one could conclude that the M.O.E. is more sensitive than M.O.R. to production variations judging from the level of significant factors. A single linear regression of M.O.R. on compression ratio shows a high level of correlation (r= 0.761 or r = 0.584 for boards made by either fast or slow closing speed respectively; (see also Figures 6 and 7). The very close correlation between board M.O.R. and M.O.E with compression ratio makes it reasonable to think that under the same manufacturing conditions, a board's M.O.R. could be predicted from M.O.E. By using simple linear regression equation, it was possible to predict M.O.E. (see Table 5). If a board's compression ratio is known, then the equation can be expressed thus:

Y_f = 106,794.7 + l59,634.6X ± 45,478 (3)

and/or

Y_s = 101,185.6 + 150,778. 1X ± 69,379 (4)

where Y_f or Y_s is M.O.E. for either fast or slow closing speed and other parts of the equation, it could be seen that M.O.E. could be increased at the same compression ratio by merely increasing the press closing speeds. This is in keeping with the findings of Heebink et al [15] and Geimer et al [22] This can be explained by the density profile, which leaves a very high-density outer surface at the region of maximum stress concentration. Figures 6 and 7 show the effects of Compression Ratio on Modulus Of Elasticity (M.O.E.).

(iii) internal Bond (I.B):- The result of the effects of production variables used in this study on Internal Bond is presented in Table 1 and Figure 3. Table 4 presents the result of factorial analysis showing the effects of production parameters on the Internal Bond. From the Table, it could be seen that effects due to furnish composition, interaction between board specific gravity and furnish. Composition and interaction between board specific gravity and press closing speed as well as interaction involving all the three production variables on Internal Bond were all significant at one per cent level. However, the effects of press closing speed and furnish were all not found to have significant effects on (lB). The import of the significance of the third order interaction is that all factors considered in this study influence board properties (IB). Again, what this means, in this particular study, is that for boards made of same manufacturing conditions, press closing speed is significant but this can not be extended to boards made of different furnish even though the specific gravity may be same. This is because the relative differences in volume of chips will create different density profile at the same press closing speed. The level of significance at the third order interaction level confirms earlier beliefs that press speed can be used to create density profile and enhance Internal Bond [14, 15]. A regression analysis of internal bond on compression ratio presents a low inverse relation (r = - 0.263 or r = - 0.45 for boards made by either fast or slow press closing speed respectively). This is in agreement with the work of Vital et al [5] in which they used tropical hardwood furnish for particleboard production. Vital et al [5] noted that the compaction ratio of 1.2 to 1.6 is about ideal for optimum board properties. It is thus reasonable to attribute the low 1B of boards made with all pine furnish and the three layer boards in which resin application was segregated to a lower level of resin received per pine particle and the high 1B properties of the high specific gravity hard maple to the high percentage of adhesive received per maple particle. The above analogy was based on the well above optimal compression ratios of boards made with all pine furnish (1.94 and 1.67 for 0.7 and 0.6 specific gravity boards respectively) and significantly lower compaction ratios of boards made with all maple furnish (0.9 and 1.04 for 0.6 and 0.7 specific gravity boards respectively. In the latter case, higher adhesive level helped to increase bond quality. This is in agreement with the findings of Post [19], Maloney [6] and Duncan [40] With a simple linear equation, it was possible to predict the Internal Bond of laboratory made boards using the equation (see Table 5) given below:-

$Y_f = 308.75 - 41.3X \pm 51.0$ (5)

and/or

$Y_s = 266.3 - 12.35X \pm 90.6$ (6)

Where Y_f and Y_s are Internal Bond properties for either fast or slow closing speed respectively and X is as previously defined while ± 90.6 and 51.0 are error terms as previously defined. Figures 8 and 9 show the effects of compression ratios on internal bond.

Validity of Predicted mechanical Properties:- Table 5 shows the results of turkey studentized test between the means of experimental values and the predicted values [41]. No significant difference were observed between the means for IB, M.O.R. and M.O.E. respectively except for 0.6 specific gravity board made from Hard maple furnish and 0.7 specific gravity board made from 3-layer board both of which were made by slow press closing speed where M. O.R. were different.

CONCLUSIONS AND RECOMMENDATIONS

(1) Particleboard properties are determined by manufacturing parameters, but unfortunately each parameter while

enhancing certain properties may also have adverse effects on other properties or increase cost of production. As such, selection of parameters have to be end use oriented.

(2) In general M.O.R and M.O.E in bending of particleboard increase as the board specific gravity is increased if other manufacturing conditions were the same while the IB decreases.

(3) The M.O.R and M.O.E of a homogenous random mixed particle board made with mixture of low density and high density species increase as the percentage of the low density and high density species increase as the percentage of the low density species in the board is increased.

(4) All hard maple furnish (a hard wood species) cannot be used to manufacture medium density particleboard and at same time employ slow press closing speed because the properties of the board fell below the minimum requirements set by the Commercial Standard - CS 236 -66.

(5) It is possible to accurately estimate a particle M.O.R and M.O.E in bending as well as Internal Bond (IB) properties of flat pressed medium density particleboard if the compaction ratio and press closing speed are known while other parameters are constant.

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Table 1: Properties of Urea for Maldehyde Bonded Flat Pressed Medium Density Particleboard as Influenced by Production Variables

Type of Wood Furnish Used in Board	Specific Gravity of Board	Moisture Content (%)	Modulus of Rupture (M.O.R.) (N/mm^2)	Modulus of Elasticity (M.O.E.) (N/mm^2)	Internal Bond N/mm^2
		Fast Press Closing Speed Treatment			
Pine	0.705	8.22	43.065	2916.5	1.481
"	0.604	8.44	36.458	2406.3	1.508
Maple	0.702	8.66	23.695	2268.4	1.632
"	0.593	8.45	20.946	1592.7	1.850
Random Mixture[a]	0.697	8.20	35.660	2420.1	2.256
" "	0.607	8.58	30.002	1889.2	2.043
3 - Layer[b]	0.602	8.50	35.122	2316.6	1.485
" "	0.595	8.38	27.612	1847.8	1.709
		Slow Press Closing Speed Treatment			
Pine	0.692	8.50	38.125	2792.4	1.756
"	0.593	8.47	26.538	1792.6	1.298
Maple	0.700	8.58	30.468	2199.4	2.594
"	0.581	8.05	16.964	1358.3	1.203
Random Mixture[a]	0.698	8.52	41.762	2861.3	2.415
" "	0.597	8.69	30.840	1647.8	1.836
3 - Layer[b]	0.704	8.50	38.764	2289.1	1.094
" "	0.588	8.39	26.138	1716.8	1.484

Legend: * = Mean property values are based on weighted average of 16 test specimens and original data were obtained in British units.

a = Panel made from furnish mixture made of 40 per cent Maple and 60 per cent Pine, based on Oven - dry weight of chips.

b = 3-Layer board constructed of 50 per cent of all Maple surfaces and 50 per cent of all Pine core based on Oven - dry weight basis.

Table 2: Summary Of The Results Of Factorial Analysis Showing The Effects Variables Rupture Of Flat Pressed Medium Density Urea Formaldehyde Bonded Particleboard

SOURCE	DEGREE OF FREEDOM	SUM OF SQUARES x 10^6	MEAN SQUARE X 10^6	F
MAIN EFFECTS:-				
A	3	22.58	7.53	34.3**
B	1	29.65	29.65	135.1**
C	1	1.91	1.91	8.7**
FIRST ORDER INTERACTION:				
AB	3	1.75	0.58	2.1 NS
BC	1	0.56	0.56	2.7 NS
AC	3	5.12	1.71	7.8**
SECOND ORDER INTERACTION:-				
ABC	3	0.60	0.20	O.92NS
ERROR	48	10.53	0.22	
TOTAL	63	72.68		

Legend: = ** Significant at one per cent level

= NS Not Significant

= A,B,C = Furnish composition, Board specific gravity and Press closing speed, respectively

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Table 3: Summary Of Factorial Analysis Showing The Effects Of Production Variables On The Modulus Of Elas Ticity Of The Resultant Flat Pressed Medium Density Urea Formaldehyde Bonded Particleboard

SOURCE	DEGREE OF FREEDOM	SUM OF SQUARES X 10^6	MEAN SQUARE X 10^6	F
MAIN EFFECTS:-				
A	3	7.05	2.35	12.06 **
B	1	0.55	0.55	2.80 NS
C	1	17.88	17.88	91.75 **
FIRST ORDER INTERACTION:				
AB	3	24.95	8.32	42.67 **
BC	1	10.65	10.65	54.63 **
AC	3	3.18	1.06	5.44 **
SECOND ORDER INTERACTION:-				
ABC	3	5.84	1.95	9.99 **
ERROR	48	9.35	0.19	

Legend: A,B,C, = Furnish composition, Board specific gravity and Press closing speed, respectively.

** = Significant at one per cent level

NS = Not significant.

Table 4: Summary Of Factorial Analysis Showing The Effects Of Production Variables On Internal Bond Of The Resultant Flat Pressed Medium Density Urea Formaldehyde Bonded PARTICICLEBOARD

SOURCE	DEGREE OF FREEDOM	SUM OF SQUARES X 10^6	MEAN SQUARE X 10^6	F
MAIN EFFECTS:-				
A	3	13.37	4.46	18.74 **
B	1	0.73	0.73	3.80 *
C	1	0.22	0.22	0.94 NS
FIRST ORDER INTERACTION:				
AB	3	4.09	1.36	5.73 **
BC	1	1.44	1.44	6.06 **
AC	3	1.26	0.42	1.77 NS
SECOND ORDER INTERACTION:-				
ABC	3	4.59	1.53	6.43 **
ERROR	48	11.42	0.24	

Legend: ** = Significant at one per cent level.

* = Significant at five per cent level.

NS = Not significant.

A,B,C, = Furnish composition, Board specific gravity and Press closing speed, respectively.

Table 4: Summary Of Factorial Analysis Showing The Effects Of Production Variables On Internal Bond Of The Resultant Flat Pressed Medium Density Urea Formaldehyde Bonded PARTICICLEBOARD

SOURCE	DEGREE OF FREEDOM	SUM OF SQUARES X 10^6	MEAN SQUARE X 10^6	F
MAIN EFFECTS:-				
A	3	13.37	4.46	18.74 **
B	1	0.73	0.73	3.80 *
C	1	0.22	0.22	0.94 NS
FIRST ORDER INTERACTION:				
AB	3	4.09	1.36	5.73 **
BC	1	1.44	1.44	6.06 **
AC	3	1.26	0.42	1.77 NS
SECOND ORDER INTERACTION:-				
ABC	3	4.59	1.53	6.43 **
ERROR	48	11.42	0.24	

Legend: ** = Significant at one per cent level.

* = Significant at five per cent level.

NS = Not significant.

A,B,C, = Furnish composition, Board specific gravity and Press closing speed, respectively.

Table 5: Predicted Best Estimate[k] Of Flat Pressed Medium Density Urea Formaldehyde Bonded Particleboard Bending And Internal Bond Properties Under Manufacturing Conditions Stated

Type of Wood Furnish Used in Board Making	Board Specific Gravity	Modulus of Rupture (M.O.R.) N/mm²	Modulus of Elasticity (M.O.E.) N/mm²	Internal Bond N/mm²
		FAST PRESS CLOSING SPEED		
Pine	0.7	43.76 NS	2916.48 NS	1.481 NS
"	0.6	34.99 "	2406.27 "	1.508 "
Maple	0.7	31.95 "	2268.38 "	1.625 "
"	0.6	23.15 "	1585.79 "	1.850 "
Random Mixture[a]	0.7	37.08 "	2433.86 "	2.256 "
" "	0.6	28.31 "	1889.16 "	2.043 "
3 - Layer[b]	0.7	36.34 "	2316.64 "	1.495 "
" "	0.6	27.57 "	1847.80 "	1.708 "
		SLOW PRESS CLOSING SPEED TREATMENT		
Pine	0.7	37.40 NS	2785.48 NS	1.756 NS
"	0.6	28.63 "	1792.64 "	1.298 "
Maple	0.7	28.97 "	2199.40 "	2.594 "
"	0.6	20.20 *	1368.27 "	1.204 "
Random Mixture[a]	0.7	41.28 NS	2861.33 "	2.415 "
" "	0.6	32.17 "	1647.85 "	1.936 "
3 - Layer[b]	0.7	34.21 *	2289.06 "	1.094 "
" "	0.6	25.44 NS	1716.80 "	1.484 "

Legend: K = Estimated data were collected in British Units and converted to S.I. Units by multiplying with appropriate factor.

NS = Predicted data is not significantly different from the means of test results in a student "t" test.

* = Predicted means is significantly different from means of experimental results (0.05 level).

a,b = As previously defined in Table 1.

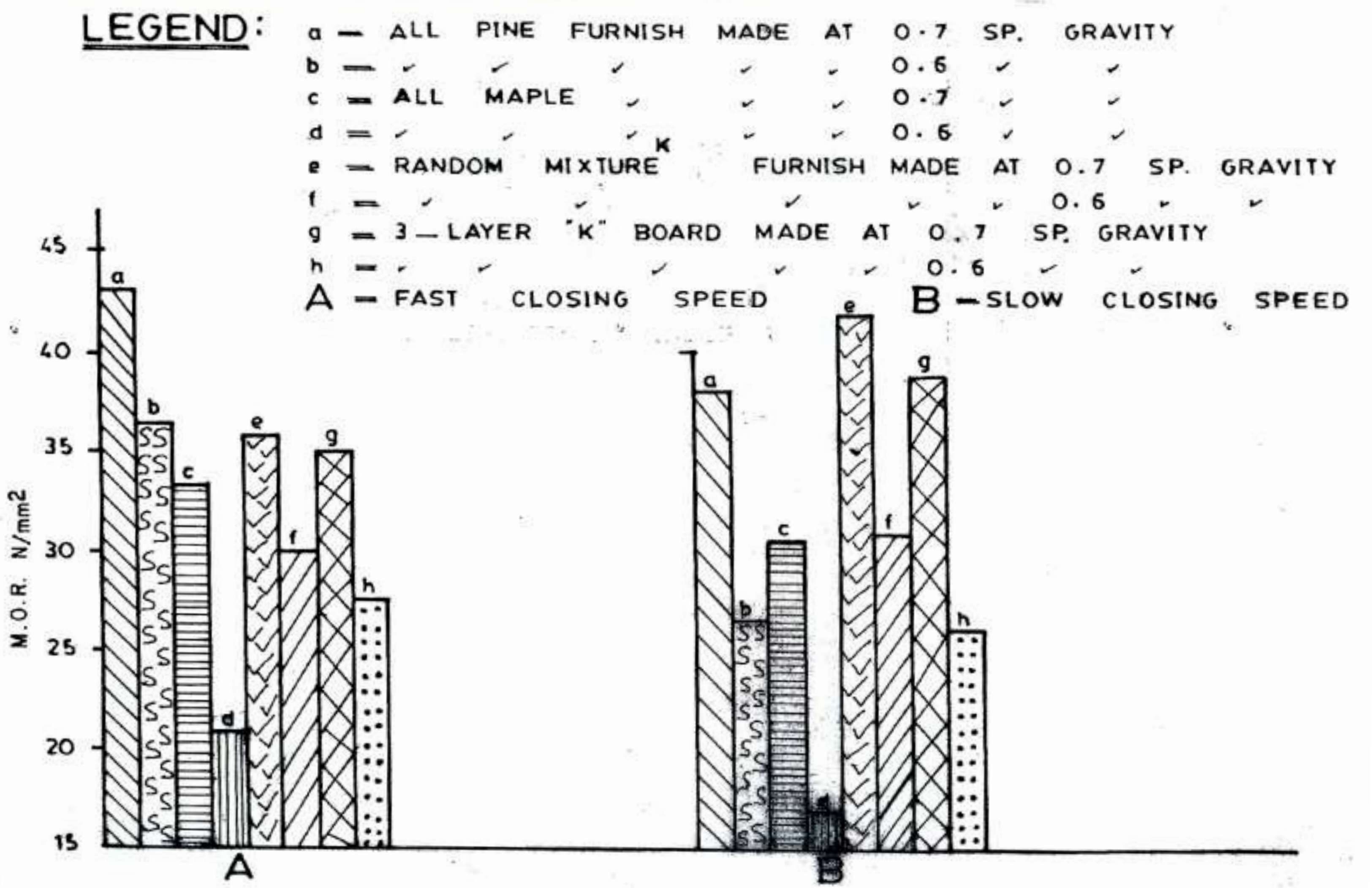

Fig. I. The effects of furnish type and board specific gravity on modulus of rupture of particle-board manufactured under different speeds.

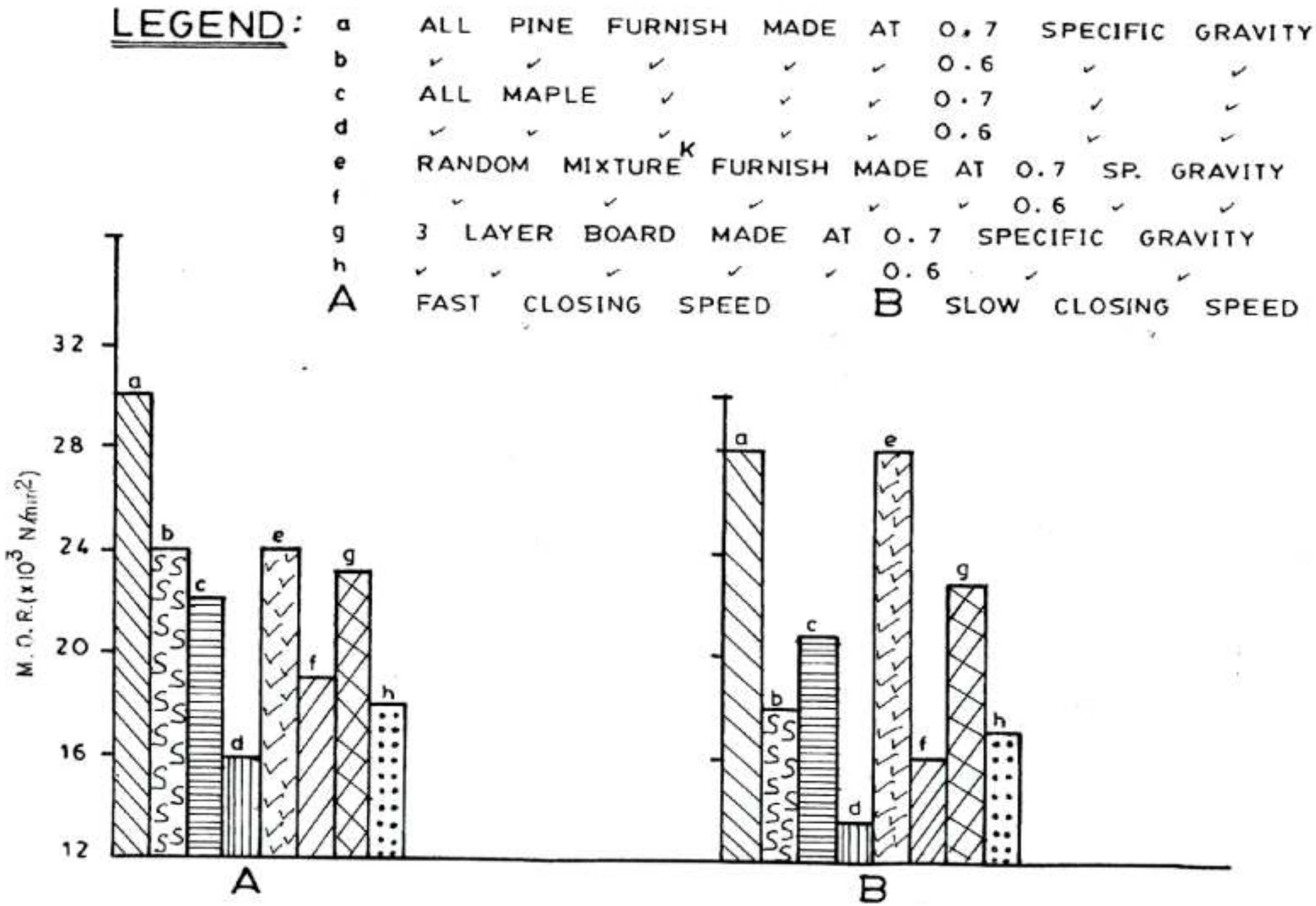

Fig. 2. The effects of furnish type and board specific gravity on modulus of elasticity of particle-board manufactured under different speeds.

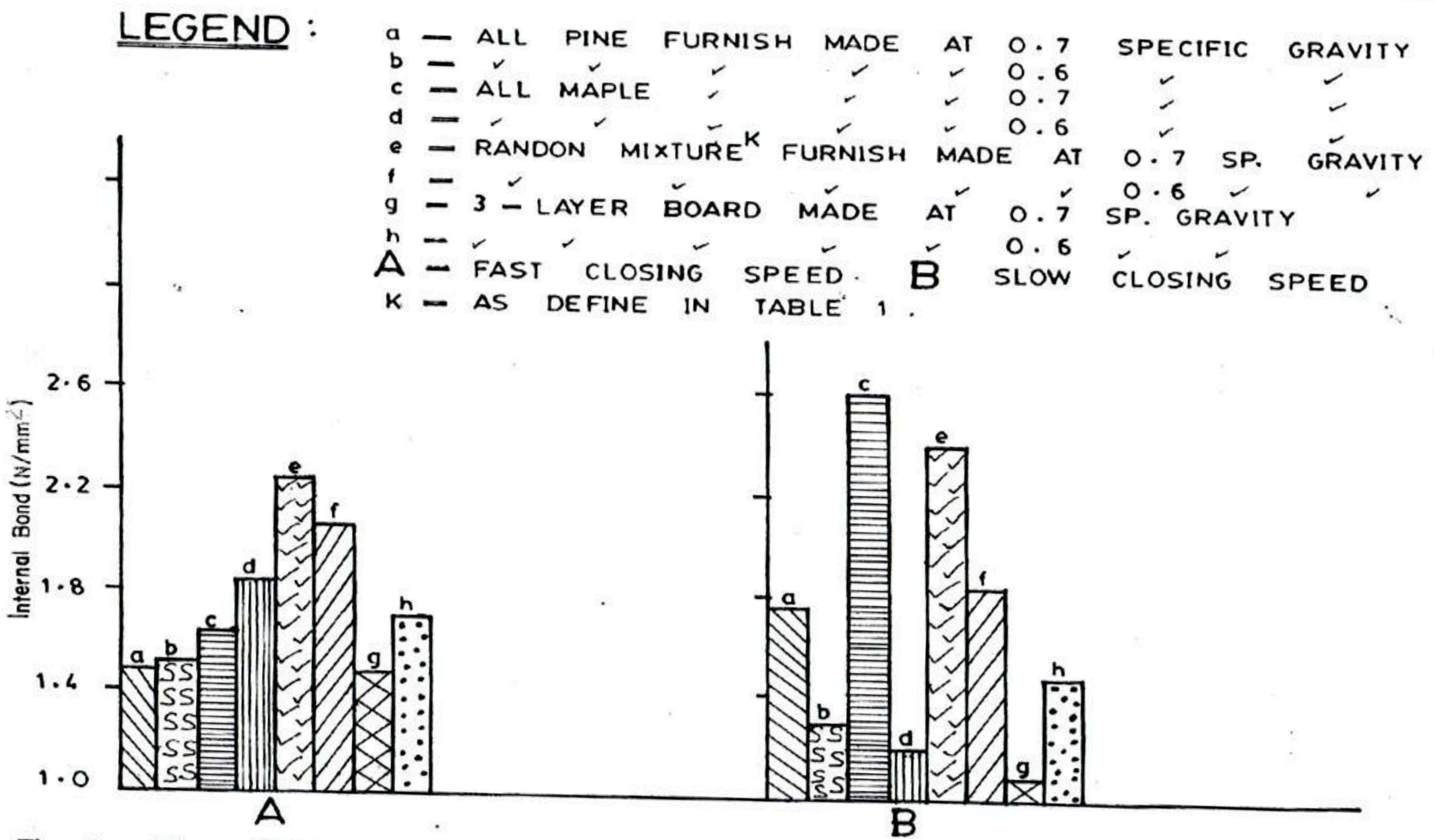

Fig. 3. The effects of furnish type and board specific gravity on internal bond of flat pressed medium density particle board manufactured under different conditions

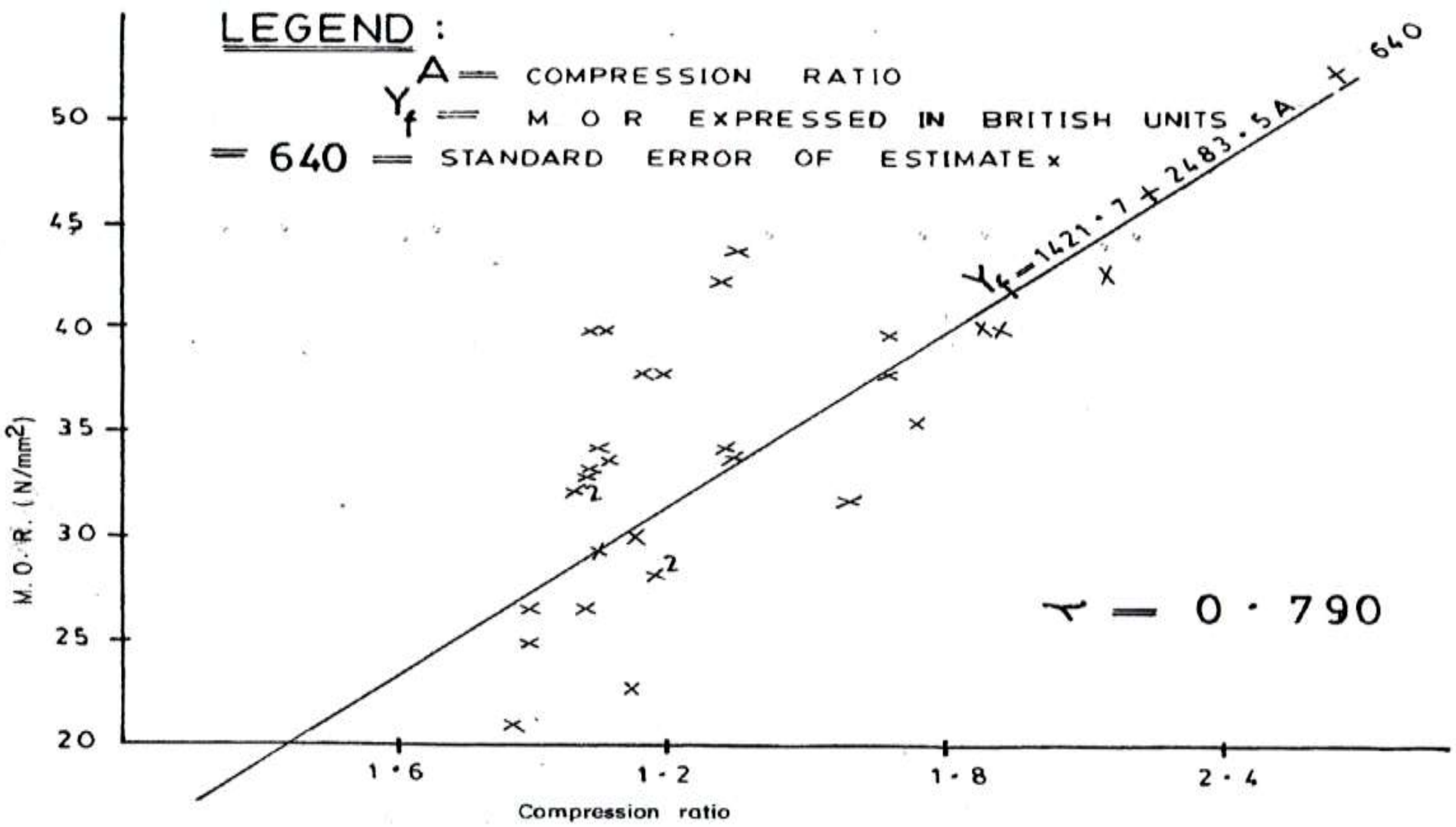

Fig. 4· The effects of compression ratio on modulus of rupture of particleboard produced by fast press closing speed.

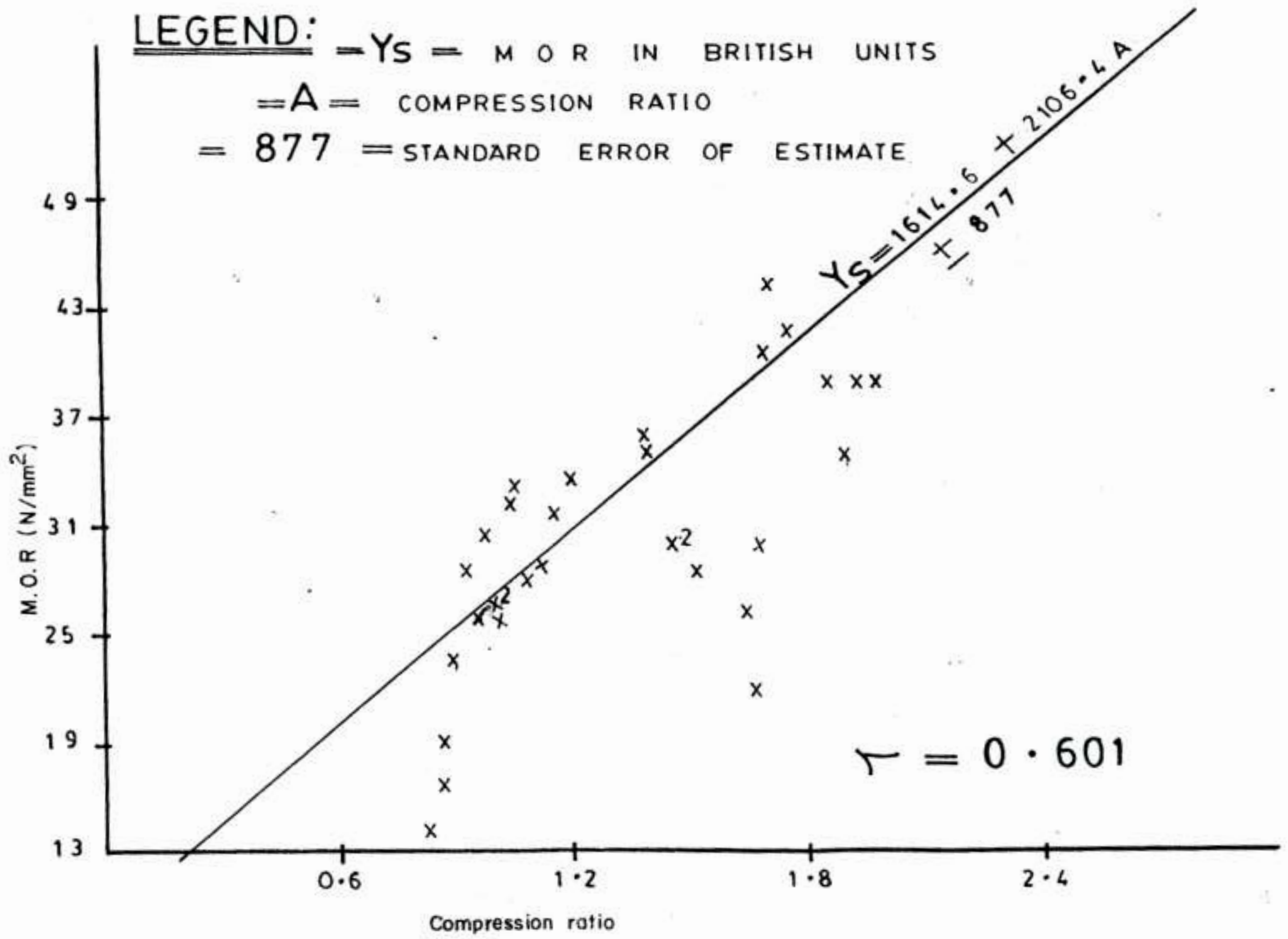

Fig. 5. The effects of compression ratio on modulus of rupture of particleboard produced by slow press closing speed.

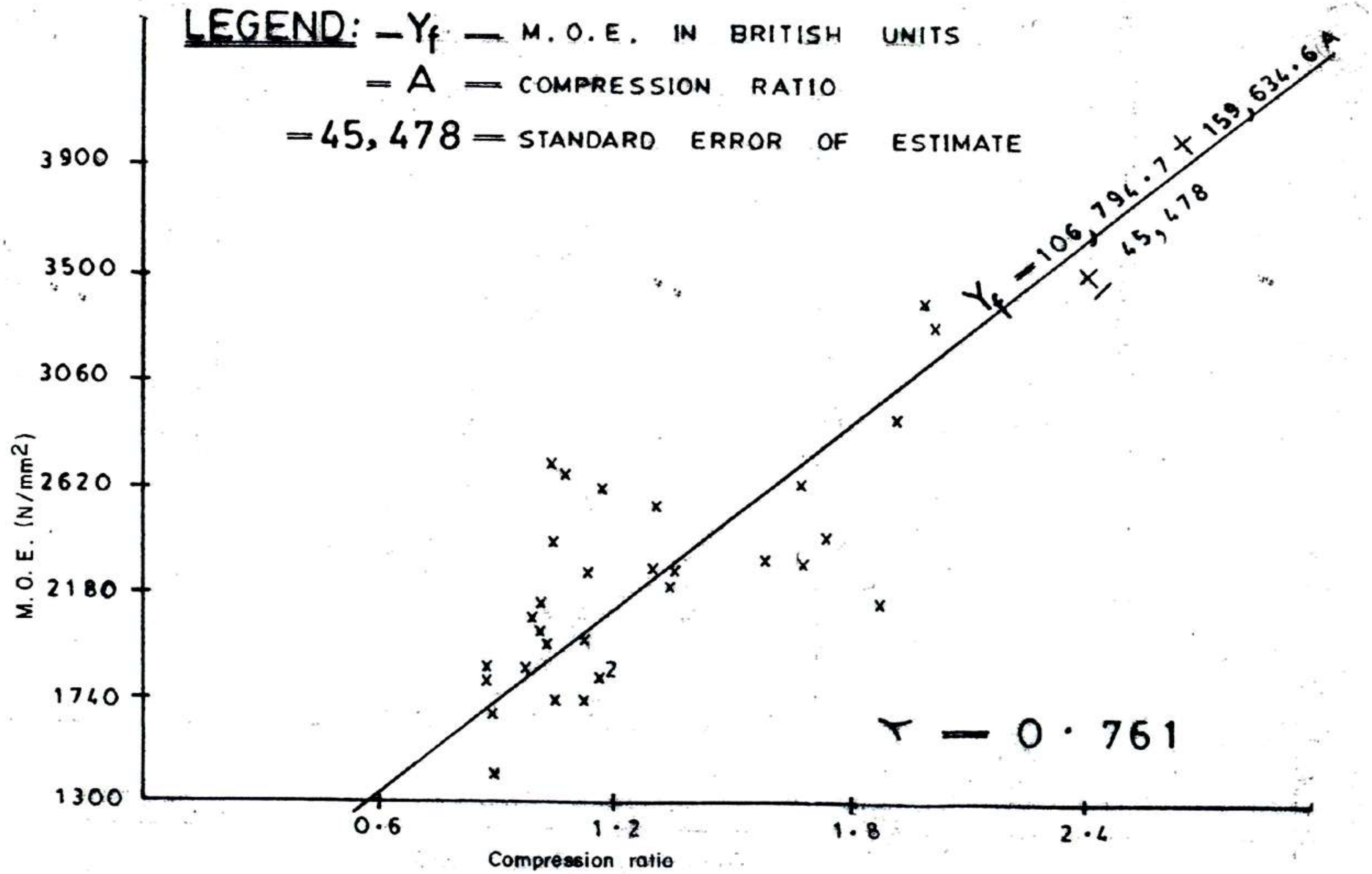

Fig. 6. The effectsof compression ratio on modulu of elasticity of particleboard produced by fast press closing speed.

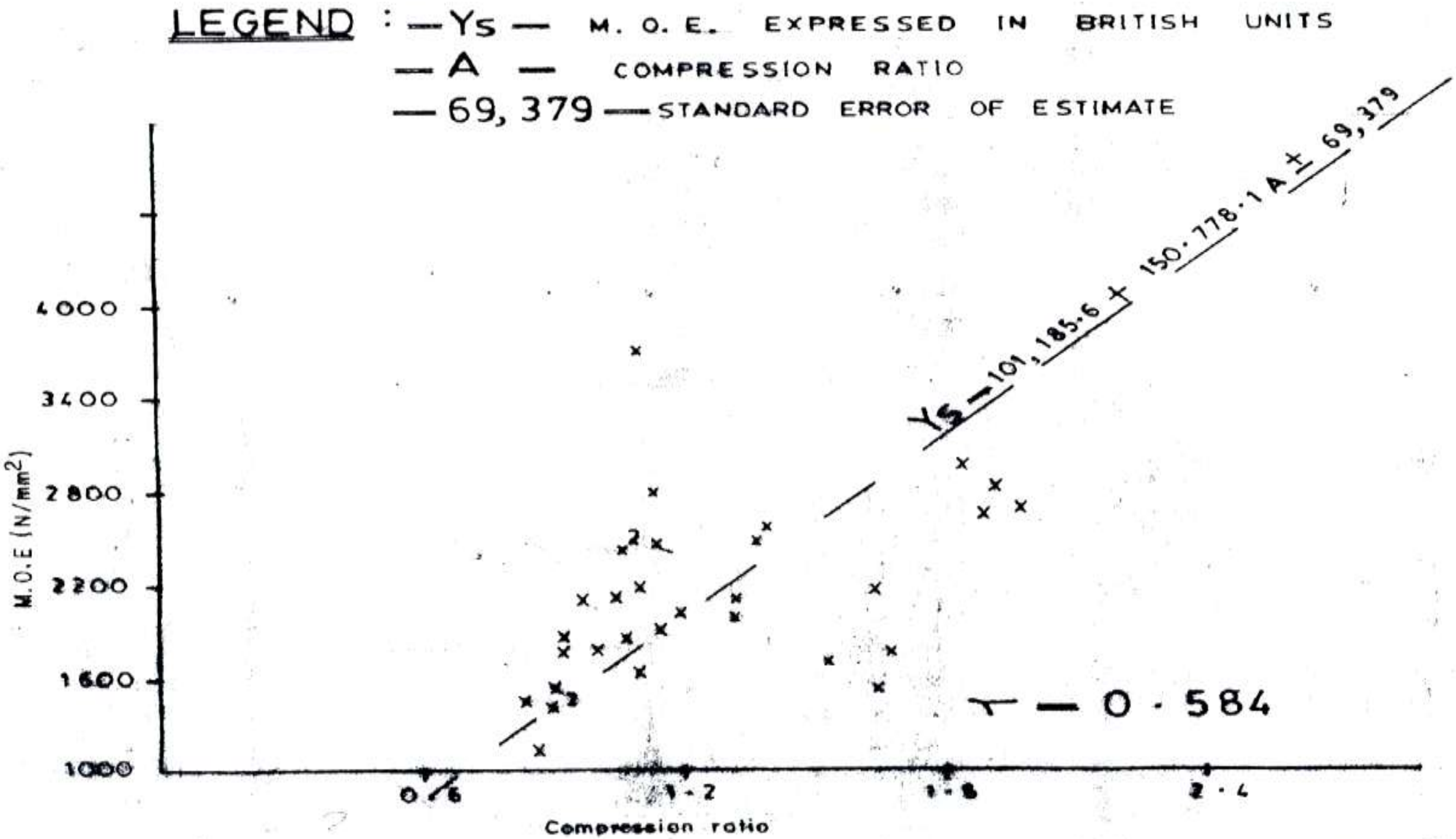

Fig. 7. The effects of compression ratio on modulus of elasticity of particleboard produced from slow press closing speed.

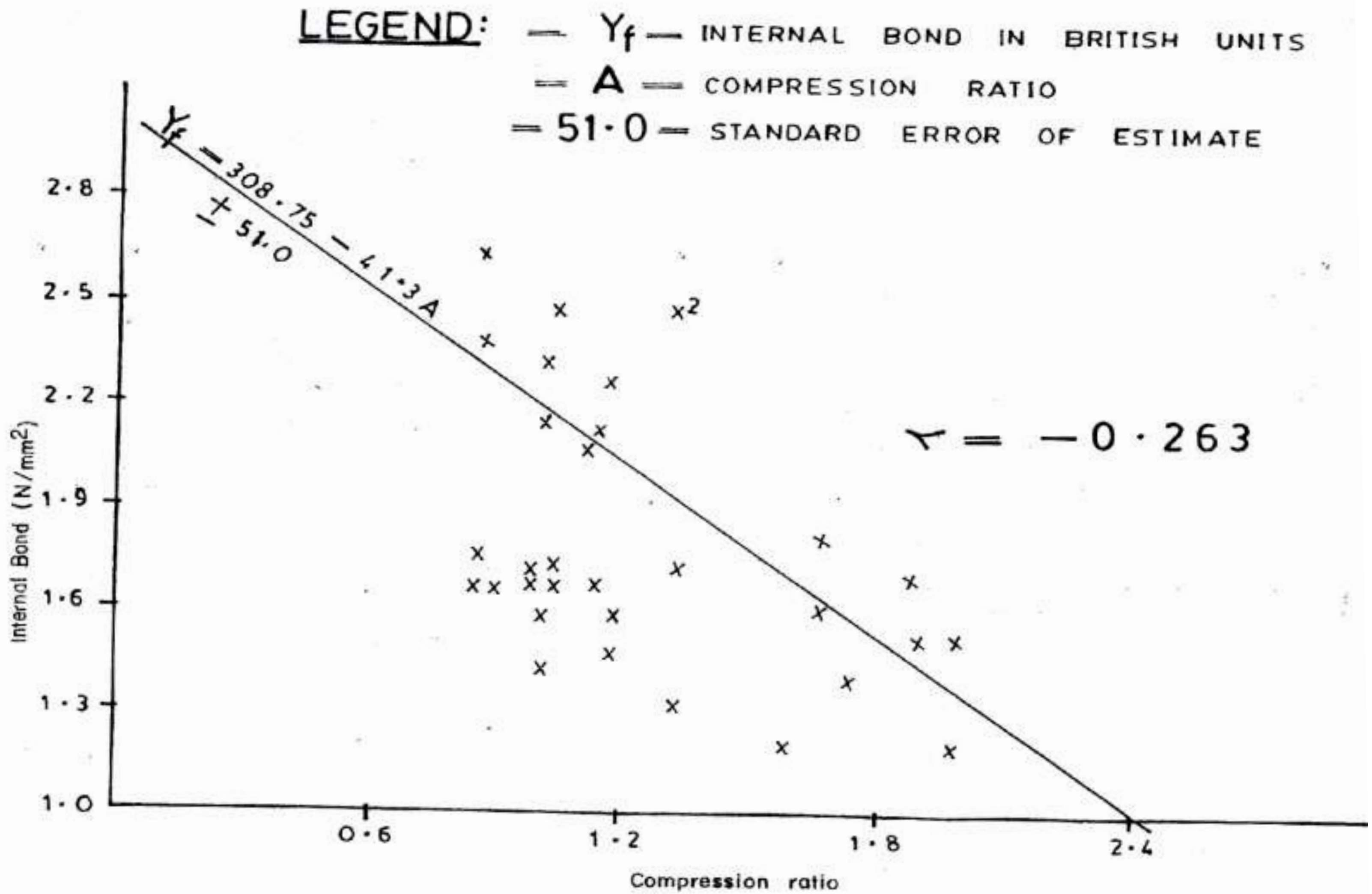

Fig. 8. The effects of compression ratio on the internal bond properties of particleboard produced by fast press closing speed.

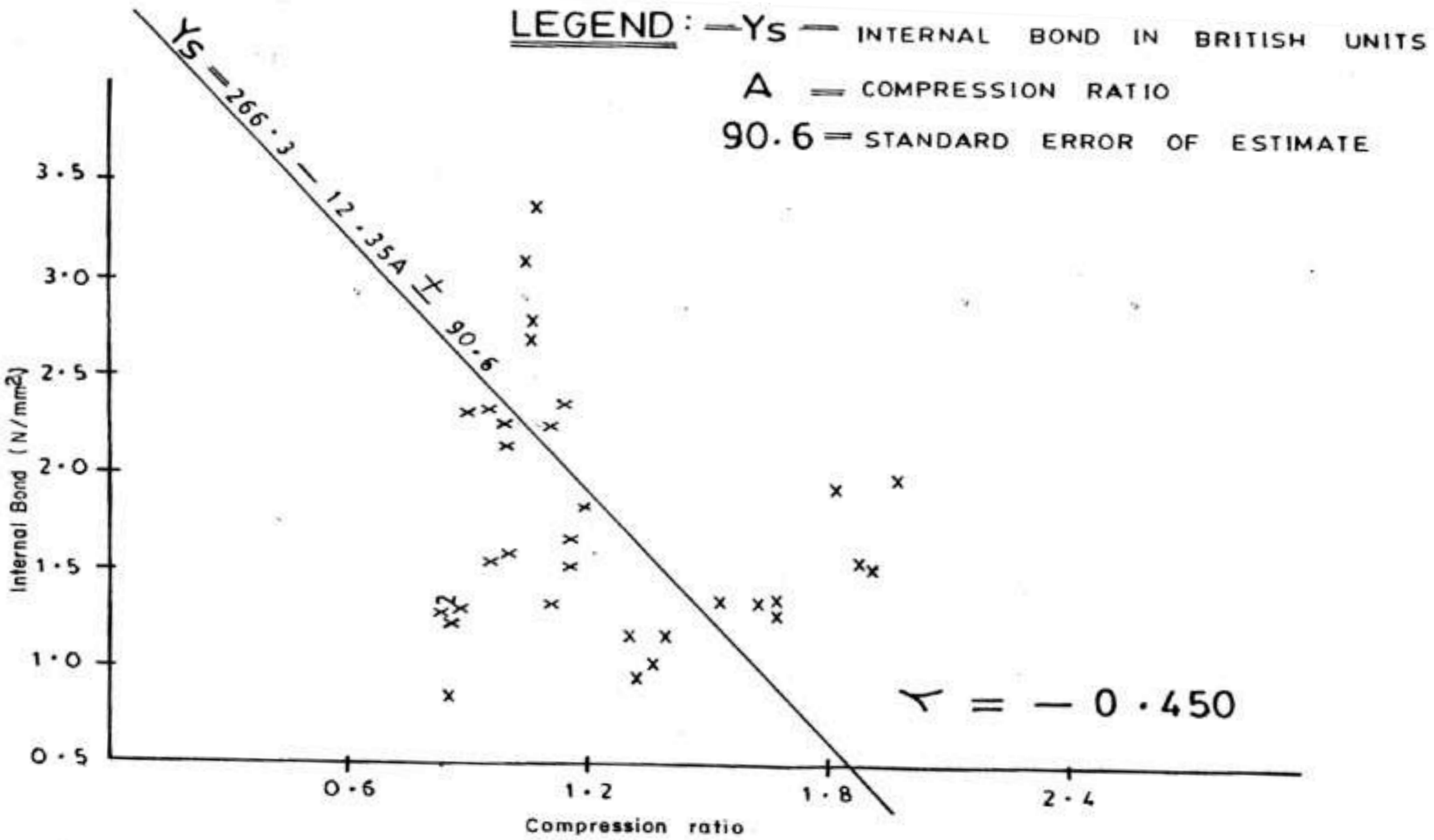

Fig. 9. The effects of compression ratio on the internal bond properties of particleboard produced by slow press closing speed.