SURFACE EVALUATION OF MELAMINE OVERLAID PARTICLEBOARD

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ABSTRACT

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By

Chun Young Lo

The objective of this study was to determine whether the results of physical surface measurement can be correlated with the average visual judgements by a number of observers of surface deterioration of overlaid particleboard.

Melamine impregnated papers were bonded to both faces of particleboard with heat and pressure in a hydraulic press. Three layers of impregnated paper sheets composed the overlays, which were overlay sheet, pattern sheet and bonding sheet. Bonding sheet impregnated with phenol formaldhyde resin was optional. Seven types of commercial particleboard were used as substrates. The suitability of a substrate for these overlays was not always apparent and must be expressed in term of the surface quality of the overlaid products after exposure to high humidity. All the specimens were first conditioned at 40% relative humidity and 70^{o} F, and then at 90% relative humidity and 70^{o} F until equilibrium was reached. Deteriorated surface profiles of overlaid board without bonding sheet were evaluated by various mathematical methods and then ranked. Visual judgements made by eight individuals resulted in a rank of all specimens. The rank correlation between the various

mathematical evaluations and the visual judgements was determined by using Spearman's formula. The test results show that the E system was rank correlated with the visual judgements, as was the Lo method. The Average method and the Standard Deviation method were not correlated with the visual judgements.

The results of the evaluation based on the E system and the Lo method revealed that surface characteristics of overlaid board were greatly affected by the substrate. Those laminates with bonding sheet have better surface quality than those without bonding sheet only under severe moisture condition. Substrates with good surface quality need no bonding sheet. Under this interpretation, substrate 10, 8 and 1 were considered as having good surface quality.

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By

Chun Young Lo

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CHAPTER 1

INTRODUCTION

Melamine overlaid particleboard consists of thin layers of melamine impregnated papers bonded to both faces of particleboard to provide protective and/or decorative surfaces.

Overlays are very essential to the wood industry. Most overlays are derived from paper products, some are polymer film. They are applied to wood products such as plywood, lumber, and composition board.

Advantages of overlaid boards are high scratch resistance, high resistance to acids, water etc. and higher mechanical strength. In addition, overlaid boards can be mass produced with a wide choice of patterns and colors and require no finishing. Among the disadvantages of board products overlaid with paper or plastic film is the instability of the surface due to thickness swelling of the substrate. The surface quality of overlaid boards is greatly dependent upon the substrate used as compared with the stability of veneered boards. The suitability of a substrate for these overlays is not always apparent and must be expressed in terms of the surface quality of the overlaid product after exposure to high humidity.

Overlays can be applied only to boards having special properties such as high compression strength and very fine surface layers. Methods of application vary with the types of overlay used, which in turn depends on the use of the end products. There are three basic types of overlays:

high density overlay, medium density overlay, and decorative overlay. All three are applied to the substrate by means of heat and pressure in hydraulic presses. Roll laminating is another method used for certain types of film that can not be satisfactorily applied to wood substrates in any other way. Roll laminating uses momentary pressure applied by a resilient roll to combine the overlay with the wood substrate panel, the adhesive having been spread on the overlay, the wood substrate or both (11).

While the human eye is very sensitive to the slightest distortions of high gloss surfaces and would therefore serve as a good indicator, classification of surfaces by visual observation could be very subjective and therefore unreliable. Physical measurement of surface profiles on the other hand requires special evaluation procedures.

The objective of this study is to determine whether the results of physical surface measurement can be correlated with the average visual judgements by a number of observers of surface deterioration of overlaid particleboard.

CHAPTER 2

THE MEASUREMENT OF SURFACES

2.1) General

The measurement of surface characteristics has been discussed for over 40 years. First attempts of surface evaluation involved the use of "sight-touch" to arrange sample specimens in a qualitative manner. Later, standards have been set with some quantitative gradation based on surface geometry (7).

To evaluate surface characteristics, a three dimensional measurement of the surface would be most desirable in order to represent the total natural characteristic of the surface. However, the difficulties involved in making such measurements are considerable so that in most cases physical surface measurement is limited to two dimensions. Subjective judgement by the sense of sight and touch on the other hand is of a three dimensional nature. Unfortunately, such evaluation cannot readily be standardized. Devices have, thus, been developed to replace "sight-touch" methods by other indirect and direct methods based on optical, accoustical, mechanical and pneumatic principles. All of these methods are comparative methods, and standards based on them are more or less arbitrary (2). Because of this fact, devices measuring the true geometry of the surface have been popularily used. The direct measurement of surfaces is based on the geometrical surface of the test specimen. The roughness factor is defined as the ratio of the area of the actual surface to that of the geometric surface (20). Deviation from the geometric surface is categorized into three categories which are refered to as roughness, waviness and lay (19).

According to the American Standard Association (19), roughness consists of the finer irregularities in the surface texture within the limits of the roughness-width cut off*. Waviness is the usually widely-spaced component of surface texture. Deviations including error of form are macro-geometrical. Lay is the direction of the predominant surface pattern. In the measurement of surface texture only deviations of roughness and waviness are of interest.

Stylus type instruments are widely used for measuring surface roughness depending on electrical amplification of the motion of a stylus perpendicular to the surface over which the stylus is traversed. The surface being traversed is cut by a plane which is perpendicular to the geometrical surface of the test specimen. The line of intersection between the cutting plane and the real surface is the real surface profile (12).

The mathematical evaluation of surface profiles has caused much confusion and misunderstanding. There are many standards for assessing roughness. But none of them can provide enough information to represent functional qualities of the surface (15). In this study, it was not attempted to determine which is the best method to evaluate surface profiles based on mathematical consideration. Rather, it was

* roughness-width cut off: The greatest spacing of repetitive irregularities to be included in the measurement of average roughness height.

attempted to find out the most applicable method which can serve as an alternative to visual judgement, which in many practical circumstances is the only criterion for the consumer to determine surface quality. Such a method would be a valuable tool for the manufacturer in predicting consumer reaction.

2.2) Methods and instruments

2.2.1) Visual and tactile methods

The reliability of touch and sight in evaluating surface texture has been studied (10, 1, 17). The human eye can detect very small variation of the angle of reflection on polished wood and nice smooth surfaces. A roughness of 0.5 μ* or even 0.1 μ with some training, can be sensed by touch. Optics of reflection deal with the relationship between the incident beam of light and the reflected beam of light. A change in angle of the incident light will cause an intensity variation of the reflected beam. The degree of change will be greater at large incident light angles than at smaller incident light angles. The human eye is capable of recognizing differences in light intensity of one percent.

Two components of light can be distinguished when a beam of light strikes an irregular wood surface covered with a transparent film. The diffuse component is responsible for the color of the surface, the specular components for its gloss.

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*$1\mu = 10^{-3}$mm

The relative intensity of both components depends on the geometry of the surface, refractive index and coefficient of absorption of the film. In the case, where light is incident on a wavy surface, the intensity of the reflected light will be considerably higher at the crests and troughs than at the slope of the waves. This is the principle of glossy surfaces which will show very small irregularities or unevenness. The observability depends not only on depth or height of the irregularities but also to a large extent on the ratio of wave, depth: wave length. When normal light is not adequate to discriminate surface roughness, the use of tactile cues is necessary. However, by using oblique light to illuminate a surface, the visual observation is as good as tactile judgements, and more rapid. Judgements made by skilled operators showed only a little more sensitivity in judgement than those made by unskilled operators under the familiar inspection condition.

2.2.2) Light methods

Several other methods are described (4) using light to analyze surfaces. One is based on image reflection, the other is the so called "light sectioning" method. The image reflection method evaluates the surface quality of a high gloss highly reflective surface by observing the distortion suffered by the reflected image of either a straight line or a regular grid pattern. Quantitative evaluation of such observation is difficult, however. In the so called "light sectioning" method, a narrow beam of light formed by a slit is focused on the surface at an acute angle. The intersection of the light beam with the surface is then observed from a position directly above the surface. Pictures of the elongated waves can be analysed and the true wave height can be calculated.

2.2.3) Mechanical systems

Devices measuring the true geometry of the surface were developed from simple mechanical systems to electro-mechanical systems by way of optical mechanical systems.

Timms (17) described an instrument in which a simple mechanical linkage is used to connect the stylus to the recorder pen, the magnification being controlled by the lever ratio in the system.

Schmalz (13) studied surface texture using a sharply pointed stylus to trace the profile and record its movements by an optical method.

In the Forster apparatus (4) manufactured by Ernst Leitz, the test specimen moves under an oscillsting stylus, connected mechanically to a tilting mirror. As the stylus oscillates, a beam of light is reflected from the mirror. The exposed portion is the air above the surface, the unexposed portion is the material, and the interface is the surface profile.

Ernest Abbott (13) in 1936, devised the "Profilometer" which converts the movements of the stylus into a corresponding alternating current and assesses the current representing the deviation of the profile from its mean line.

R. A. Hann (6) devised an apparatus consisting of three basic components: the pick up arm, the amplifier recorder and the feed mechanism. The pick up arm is fitted with strain gages which are mounted on the beam. They are so connected that vertical deflections are magnified. The probe on the pick up arm consisting of a steel ball touches the surface being studied. The size of the steel ball, 1/4 inch in diameter, is considered satisfactory for studies of finished panels, machined surfaces, and particleboard. The amplifier recorder magnifies the strain in the pick up arm and records it on a moving paper chart. The speed of the chart and the amplification can be adjusted to give varying degrees of vertical and horizontal magnification. Hann found that the results were reproducible, and that the apparatus could detect differences in surface contours of wood panels due to humidity change.

The currently used stylus instruments transfer the motion of the stylus electrically to the recording system. There are two types of transducer. One is a direct displacement type using the same principle as that employed in a phonograph. Another type integrates the rate of stylus motion to give the displacement (13). When the stylus tracer moves over the specimen at a constant speed, two components resist the motion. Horizontal movement of the stylus is resisted by friction force, requiring a greater driving force. The vertical component results in the stylus moving upward. The magnitude of this vertical component depends on the cone angle of the stylus and the coefficient of friction between the stylus and the surface. Small cone angles of the stylus will result in no vertical lifting component no matter how much horizontal force is applied. In addition, dynamic inertial forces are generated in the vertical direction which may lead to surface damage and erroneous indication of the surface profile. Therefore, the weight and cone angle of the stylus should be appropriate for the surface to be traced (13).

2.3) Evaluation

The two types of references used in the stylus type measuring technique are the true-datum method and the surface-datum method. In the true-datum method, the reference line is a straight line. In the surface-datum method, the oscillation of the stylus on the surface occurs relative to a skid or shoe of certain dimension which as it moves over the surface, does not necessarily describe a straight line but follows a second order surface characteristic which depends in part on the dimensions of the shoe. The difference between the surface and the second order curve described by the shoe is indicated by the variation of the trace from a straight line.

Two basic evaluation systems based on mathematics have been considered as national standards, namely the M (mean line) system and the E (envelope) system (12).

2.3.1) M system

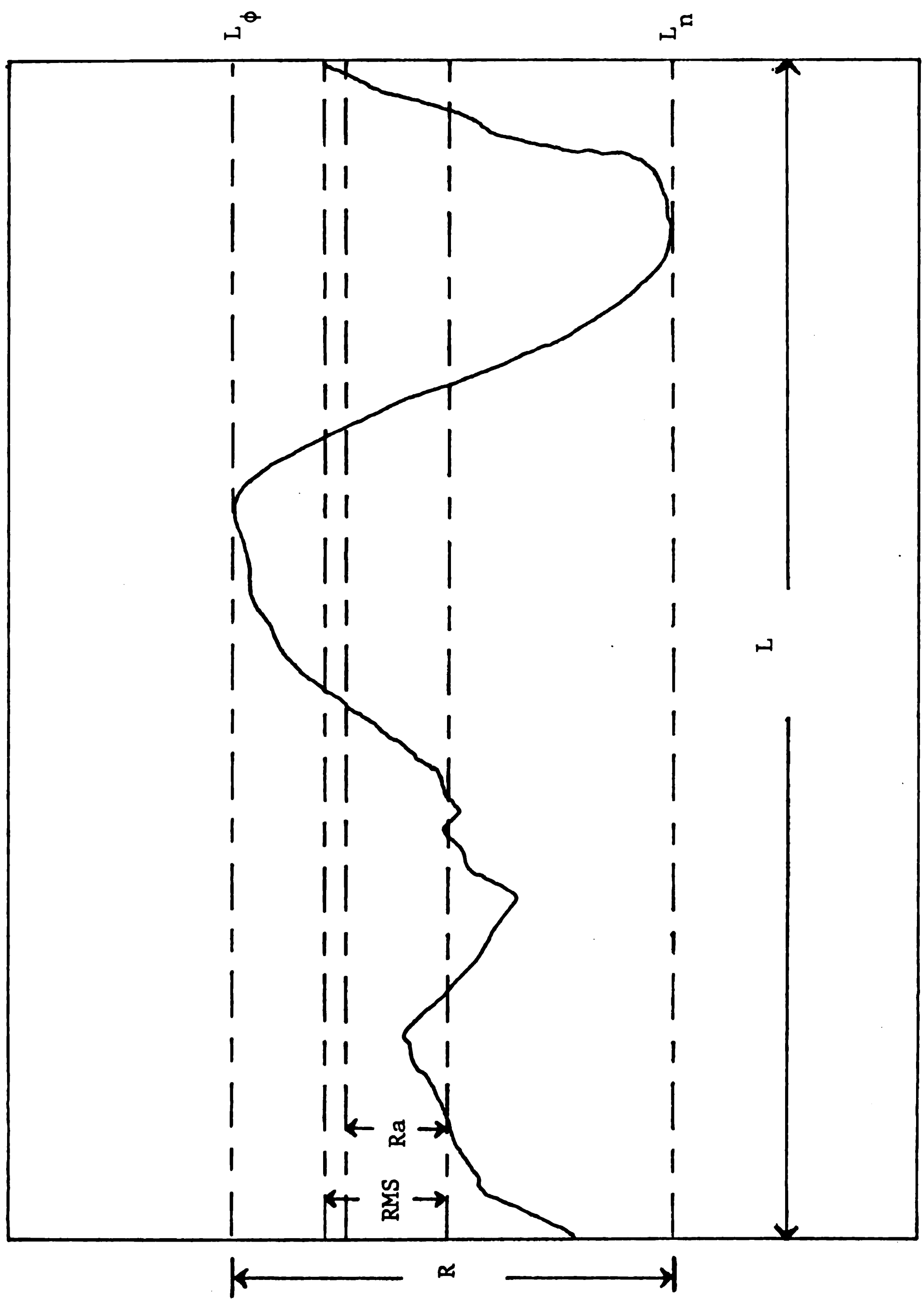
In this system the deviation of the profile from the mean line is measured. The mean line is defined by British Standard 1134 as a line conforming to the prescribed geometrical form of the profile and so placed that the sum of the squares of the ordinates between it and the profile is a minimum. A number of roughness values are defined, based on the M system, which are illustrated in Fig. 1.

a) The peak to valley value, R, is the distance between the upper and lower reference line L_ϕ and L_η.

b) The center line average value, R_a, is the arithemetic average value of the departure of the whole of the profile both above and below its mean line throughout the prescribed roughness-

FIGURE 1. Basic surface measures according to the M (mean line) system.

FIGURE 1.



width cut off in a plane substantially normal to the surface, The mathematical expression is:

$$R_a = \frac{1}{\ell}\int_o^\ell |y|\,dx$$

c) The root-mean-square value, RMS, is the geometric average value of the departure of the whole of the profile both above and below its mean line throughout the prescribed roughness-width cut off, in a plane substantially normal to the surface. The mathematical expression is:

$$RMS = \sqrt{\frac{1}{\ell}\int_o^\ell y^2\,dx}$$

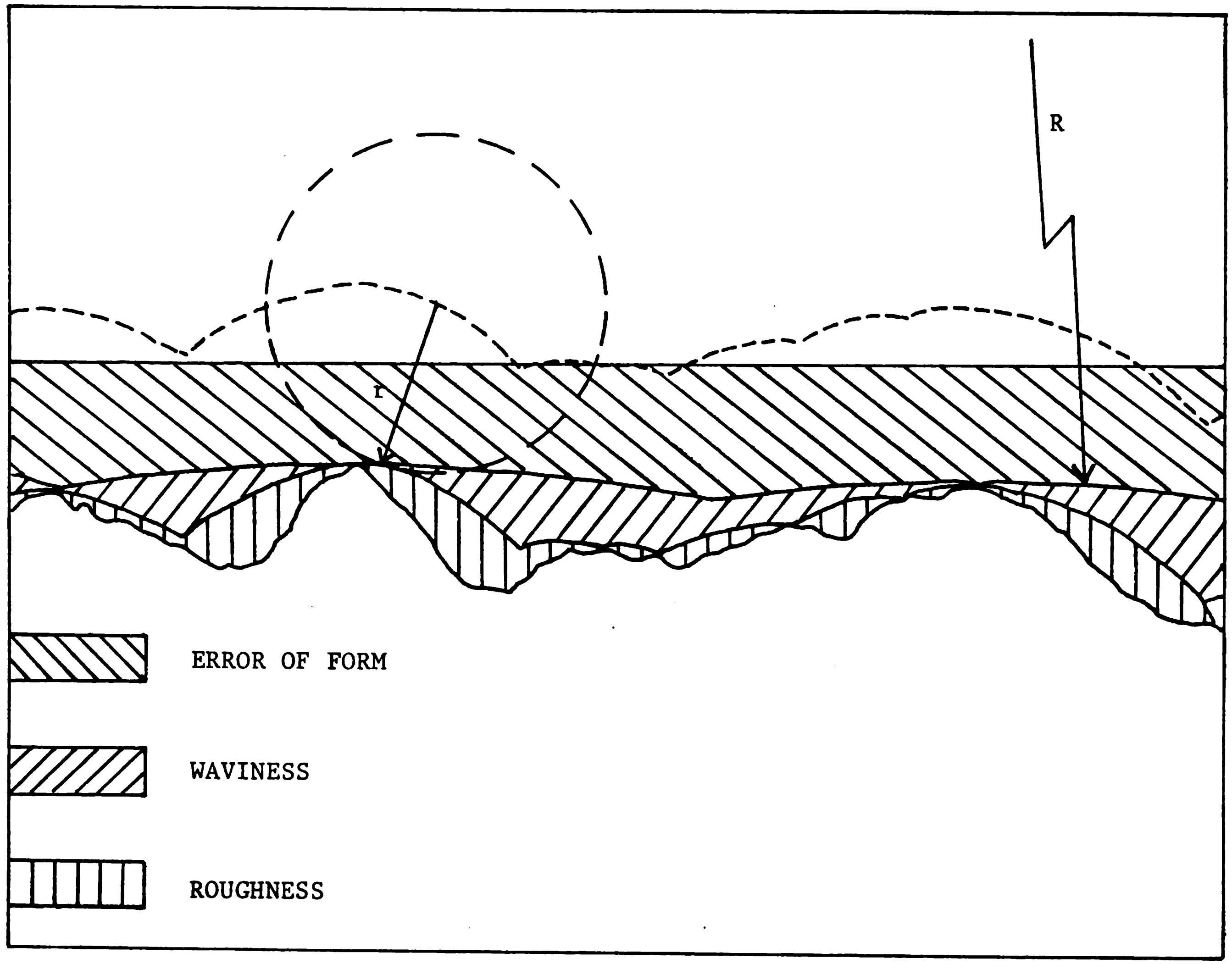
The main defect of the M system is the difficulty in determining the actual position of the mean line. In addition, the M system does not offer a clear separation of roughness, waviness and error of form. None of the above single measurements can describe the surface characteristics completely. In some cases, the center line average fails to distinguish between two different surface characteristics.

2.3.2) E system

The E system is described in Fig. 2. Two circles with different radii are rolled across the surface to be evaluated. The center of each circle produces a curve. The curve generated by the center of the large circle is called "curve of form". The curve generated by the center of the small circle is called "contacting envelope". Both the "curve of form" and the "contacting envelope" are displaced in a direction perpendicular to the geometrical profile to a position where they are contacting some of the highest peaks in the effective profile which is

FIGURE 2. Basic surface measures according to the E (envelope) system.

FIGURE 2.



the actual surface trace. The area between the geometric profile and the "curve of form" represents the "error of form", the area between the "curve of form" and the "contacting envelope" represents the waviness and the area between the "contacting envelope" and the effective profile represents the roughness.

The main defect of the E system is that the radii of the discs chosen for the determination of roughness and waviness are arbitrary. The advantage of the E system is that it offers a clear and unambiguous separation of roughness, waviness and error of form.

This ability of the E method to separate the three components of the surface profile makes it appear very suitable for the treatment of the problem at hand. It can readily be verified that surface distortions percieved by the eye as undesirable and detracting are those of relative short wavelength or period. Distortions of longer wavelength on which the former may be superimposed do not necessarily affect the value judgement of the observer. It would, therefore, be desirable to measure the objectionable deviation of the surface profile from a possibly percievable but not objectionable trend curve or curve of form. Such an evaluation could indeed simulate the judgement based on visual observation.

For these reasons, the E system was employed in the present study. In addition, several other methods, namely the Average method, Standard Deviation method and the method which was developed by the author (Lo method) were also used and are described in the following chapter.

CHAPTER 3

EXPERIMENTAL DESIGN AND PROCEDURE

3.1) Material

3.1.1) Substrate

Several commercial particleboards which have previously been described by Suchsland (18) were used as substrates (see Fig. 3 and Table 1). Of the ten types used in the previous study, three had to be eliminated because of the following reasons: No. 6 and No. 7 of the boards used before are flake boards which are not considered to be very suitable for the application of overlays. Board No. 9 developed steam blisters in the laminating process and was, therefore, eliminated.

3.1.2) Overlays

Laminating papers were obtained from Resopreg Products, Division of Pioneer Plastics Corporation.

a) Overlay Sheet:

This paper is a long fibered alpha cellulose paper weighing 20 lbs per 3,000 square feet, saturated with a specially formulated melamine formaldehyde resin designed for this purpose. The resin content is 75% by weight.

b) Pattern Sheet:

This is a "saturating grade" alpha cellulose pigmented paper,

FIGURE 3. Photograph of seven types of substrate.

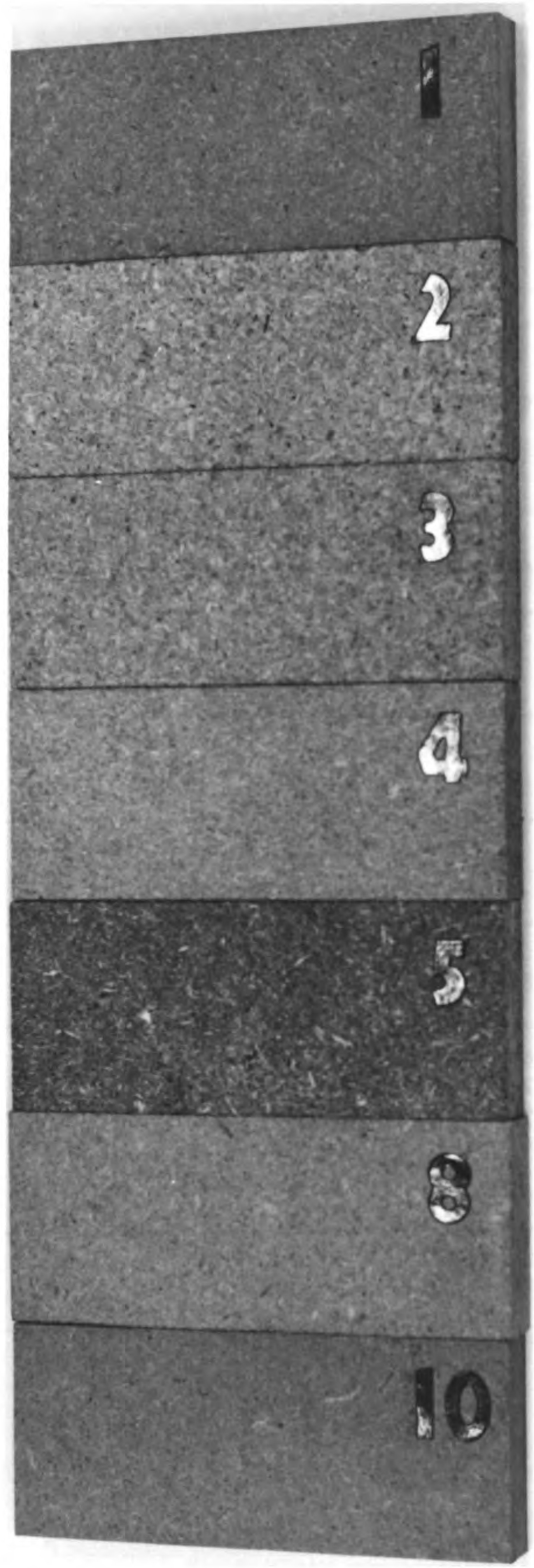


FIGURE 3.

TABLE 1. General Properties of Seven Types of Commercial Particleboard.

Board Type	Description	Thickness (in)	Specific gravity at 40% R.H.	Moisture content at 40% R.H. (%)	Moisture content at 93% R.H. (%)	Thickness swelling 40% - 93% R.H. (%)	Water absorption 24-hr. water soak (%)	Modulus of elasticity at 40% R.H. (psi x 10^{-3})	Linear expansion 40% - 93% R.H. (%)
1	Pine, homogeneous exterior	.750	.963	5.3	16.3	11.4	7.2	878	.700
2	Pine, graduated underlayment	.750	.692	7.8	16.5	5.5	4.1	478	.466
3	Pine, graduated	.750	.804	6.7	18.2	12.7	4.9	783	.650
4	Fir, graduated	.750	.732	7.4	18.5	8.8	4.2	698	.522
5	Hardwoods, graduated	.750	.761	7.0	19.1	11.6	7.9	571	.409
8	Fir, graduated	.750	.760	7.7	16.4	7.2	3.9	618	.344
10	Hardwoods, homogeneous fiberboard	.750	.693	5.7	15.4	6.3	5.2	556	.425

65 lbs basis weight, the resin is the same type of melamine formaldehyde resin as used in the overlay. Resin content is 40% by weight. The amount of pigment varies from approximately 10% up to 25% of the weight of the paper prior to saturation. The pigment is put into the paper in the original pulping stage prior to forming on the paper machine. Its function is to provide color and to increase opacity.

c) Bonding Sheet:

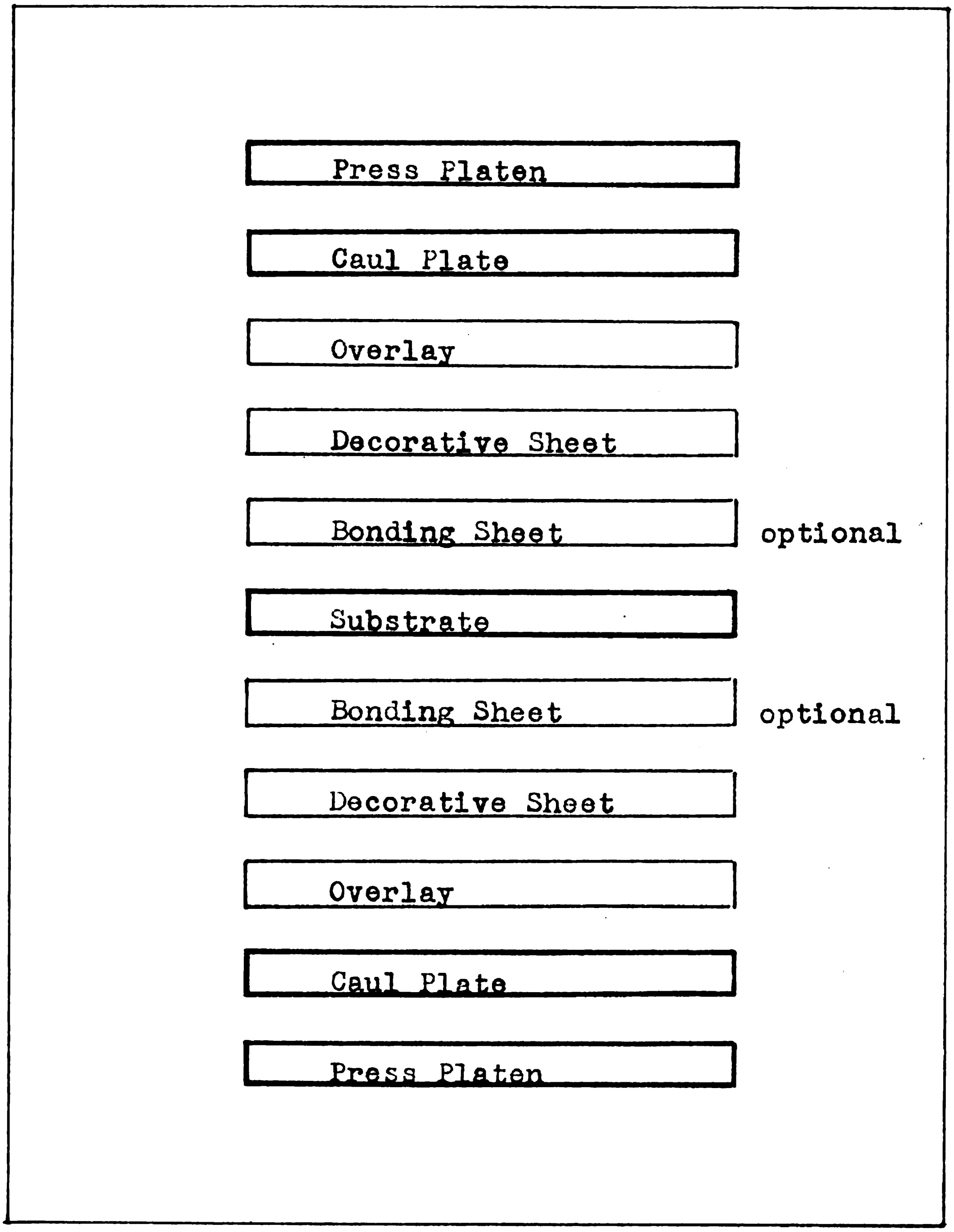
This is a natural kraft paper blending unbleached hardwood kraft for saturating capability with softwood fiber for strength and is referred to as a saturating kraft. Basis weight varies from 97 lbs to 128 lbs. The resin is a phenol formaldehyde resin. Resin content is 45%.

3.2) Laminating procedure

Twelve by twelve inch pieces were cut from each type of particleboard. Laminating papers having the same size as the substrate were arranged as shown in Fig. 4. The same construction was used on both surfaces of substrate. The laminating procedure followed the recommendations for industrial application. In a single opening oil heated press, a press cycle of 10 minutes at 250°-290° F and 300 psi pressure was used. Temperature was measured by themocouple, reading taken at the laminating surface. The same treatments were used for the laminates without using bonding sheet and also for the plain substrate of each type. The

FIGURE 4. The construction of overlays.

FIGURE 4.


Press Platen
Caul Plate
Overlay
Decorative Sheet
Bonding Sheet
optional
Substrate
Bonding Sheet
optional
Decorative Sheet
Overlay
Caul Plate
Press Platen

treated plain substrates are called compressed substrates. It should be noted here that the press cycle used caused considerable thickness compression of all specimens except type 1 which has a higher density than the others (see Table 1).

3.3) Exposure cycle

All the specimens were first conditioned at 40% relative humidity and 70° F (condition 1), and then at 90% relative humidity and 70° F (condition 2) until they reached equilibrium. Surfaces were measured at both conditions, at the same locations on the specimen.

3.4) Design of experiment

The experimental design is shown in Table 2.

3.5) Visual observation after exposure to high humidity

As explained earlier, the judgement of surface equality is basically a subjective sensation by human's sight and touch. In the case of a commercial product where appearance is an important property, visual judgement of surface quality must be recognized as an important quality control element. Any objective method which correlates well with visual evaluation results would therefore have important practical application.

Eight individuals were asked to pick the specimen with superior surface quality from randomly selected pairs of specimens. They were instructed to view the specimens at an acute angle. A certain number of

TABLE 2. Design of Experiment.

GROUP	A	B	C	D
SPECIFICATION	SUBSTRATE	COMPRESSED SUBSTRATE	OVERLAID SUBSTRATE WITHOUT BONDING SHEET	OVERLAID SUBSTRATE WITH BONDING SHEET
BOARD TYPE	1, 2, 3, 4, 5, 8, 10	1, 2, 3, 4, 5, 8, 10	1, 2, 3, 4, 5, 8, 10	1, 2, 3, 4, 5, 8, 10
SIZE	2" x 6"	2" x 6"	2" x 6"	2" x 6"
NUMBER OF SPECIMENS	7	7	7	7
EXPOSURE CYCLE	CONDITION 1 CONDITION 2	CONDITION 1 CONDITION 2	CONDITION 1 CONDITION 2	CONDITION 1 CONDITION 2
CONDITION 1	40% relative humidity, 70° F			
CONDITION 2	90% relative humidity, 70° F			

such comparative judgements resulted in a ranking of all specimens based on the surface quality as percieved by each individual.

3.6) Measuring surface profiles

The surface profiles of four groups of specimens were measured 3 inches along the central line of each specimen with a Bendix Microcorder (see Fig. 5) at condition 1 and condition 2.

3.6.1) Instrument

This instrument consists of five major units.

a) The tracer:

The tracer translates the surface irregularities into voltage changes. The tracer has a stylus which follows the irregularities of the surface. The stylus is attached to one end of a pivoted beam, the other end being connected to a transducer which transforms the physical displacement of the stylus into electrical signals which are fed to the amplimeter. The movement of the stylus is relative to a shoe. The size of the shoe is .25 in. in length.

b) The pilotor:

The pilotor drives the tracer over the surface being tested. The pilotor provides a system for driving the tracer at a speed of .005 inches per second. The pilotor consists of a drive screw mechanically driven and a ram that is free to

FIGURE 5. The Bendix Microcorder stylus instrument.

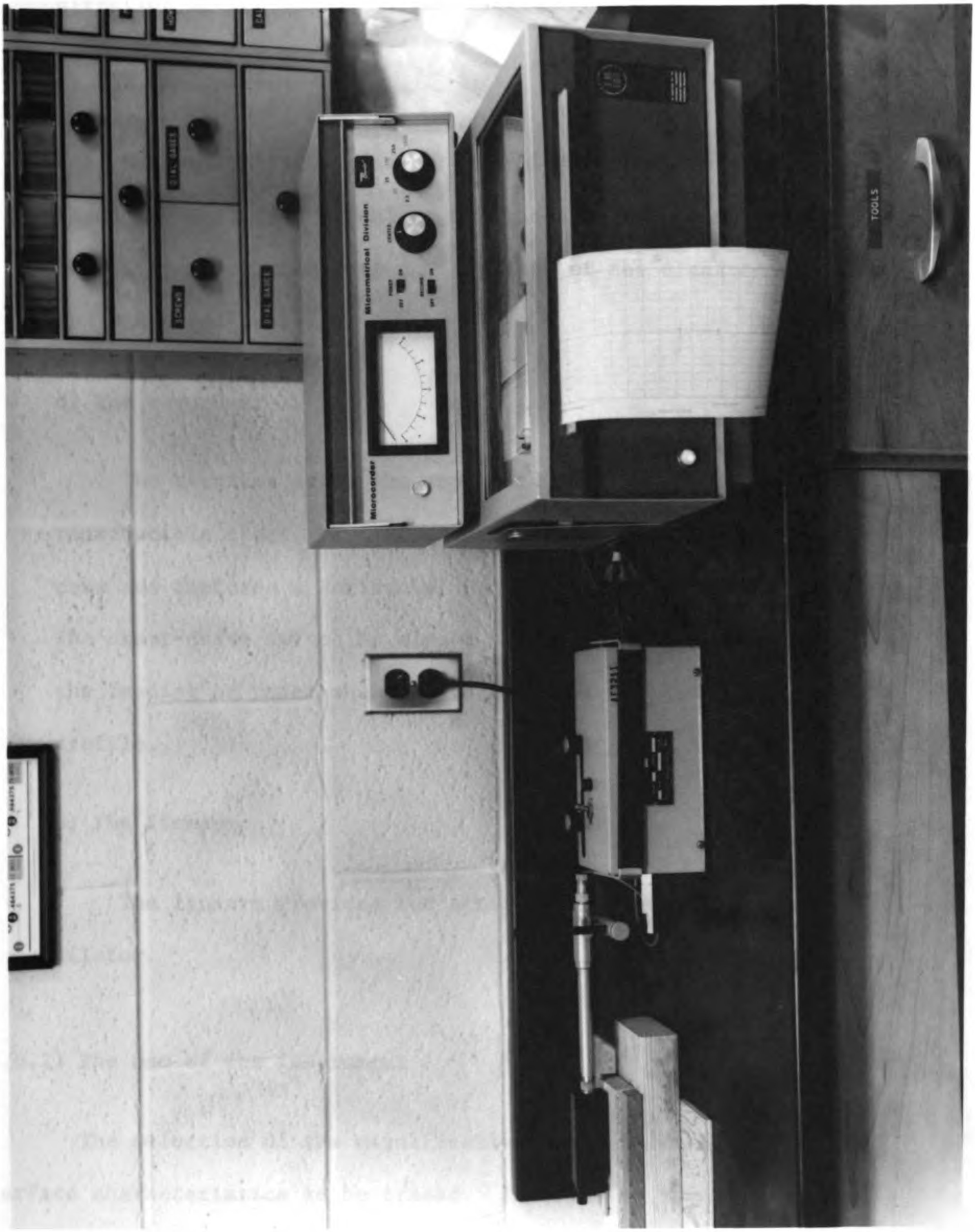


FIGURE 5.

move in a vertical direction, but is controlled in the horizontal direction by the motion of the ram.

c) The amplimeter:

The amplimeter amplifies the voltage from the tracer and feeds the amplified signal to the recorder. The amplimeter is housed in a portable case and consists of the electronic system and a control panel.

d) The recorder:

The recorder draws the amplified profile on a translucent, reproducible chart. The recorder is contained in a separate case and features a Horizontal Sensitivity Selection Wheel. The chart-drive switch is also a paper feed switch to allow the feeding of paper when the recorder is not drawing a profile.

e) The linkarm:

The linkarm provides for attaching the tracer to the pilotor.

3.6.2) The use of the instrument

The selection of the magnification scale is based on the surface characteristics to be traced. In order to reveal enough variation of the surface on the chart, it is desirable to keep both the vertical and horizontal magnification at a maximum.

Limitation should be such that the drawing is kept on the chart. Sometimes, for the convenience of evaluation, a smaller scale of magnification is chosen to produce a smoother curve. Precaution must be taken to make sure that the same scales of magnification can be used at different moisture conditions without exceeding the range of the chart. The vertical magnification can be chosen from the following: 2.5, 10, 25, 100, 250, 1000, microinches per chart paper division from which 250 was chosen for this study which is a magnification of 1000 times or 4000 microinches full scale. The horizontal selection can be made from the following: .001, .002, .005, .010, .020, .050 inches per division. .050 inches per division was selected for this study which is a magnification of 10 times. The length of the trace was approximately 3 inches. Fig. 6-9 show the original profiles of group C & D specimens at condition 1 and 2.

3.6.3) The reproducibility of measurements

The reproducibility of the profiles produced from two traces over the same surface is demonstrated in Fig. 10.

FIGURE 6. The original profiles of overlaid substrate without Bonding Sheet (group C) measured at condition 1.

FIGURE 6.

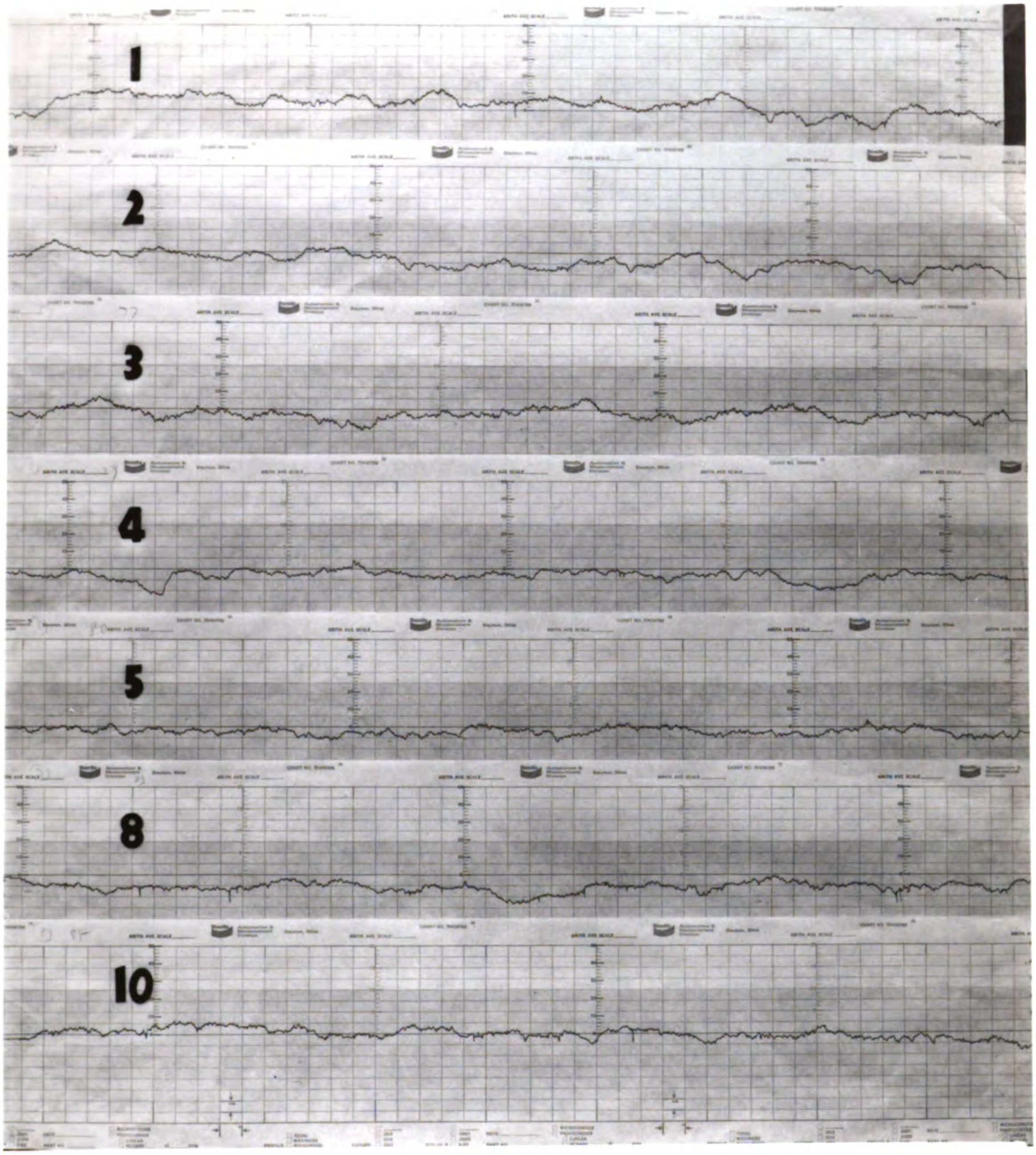


FIGURE 7. The original profiles of overlaid substrate without Bonding Sheet (group C) measured at condition 2.

FIGURE 7.

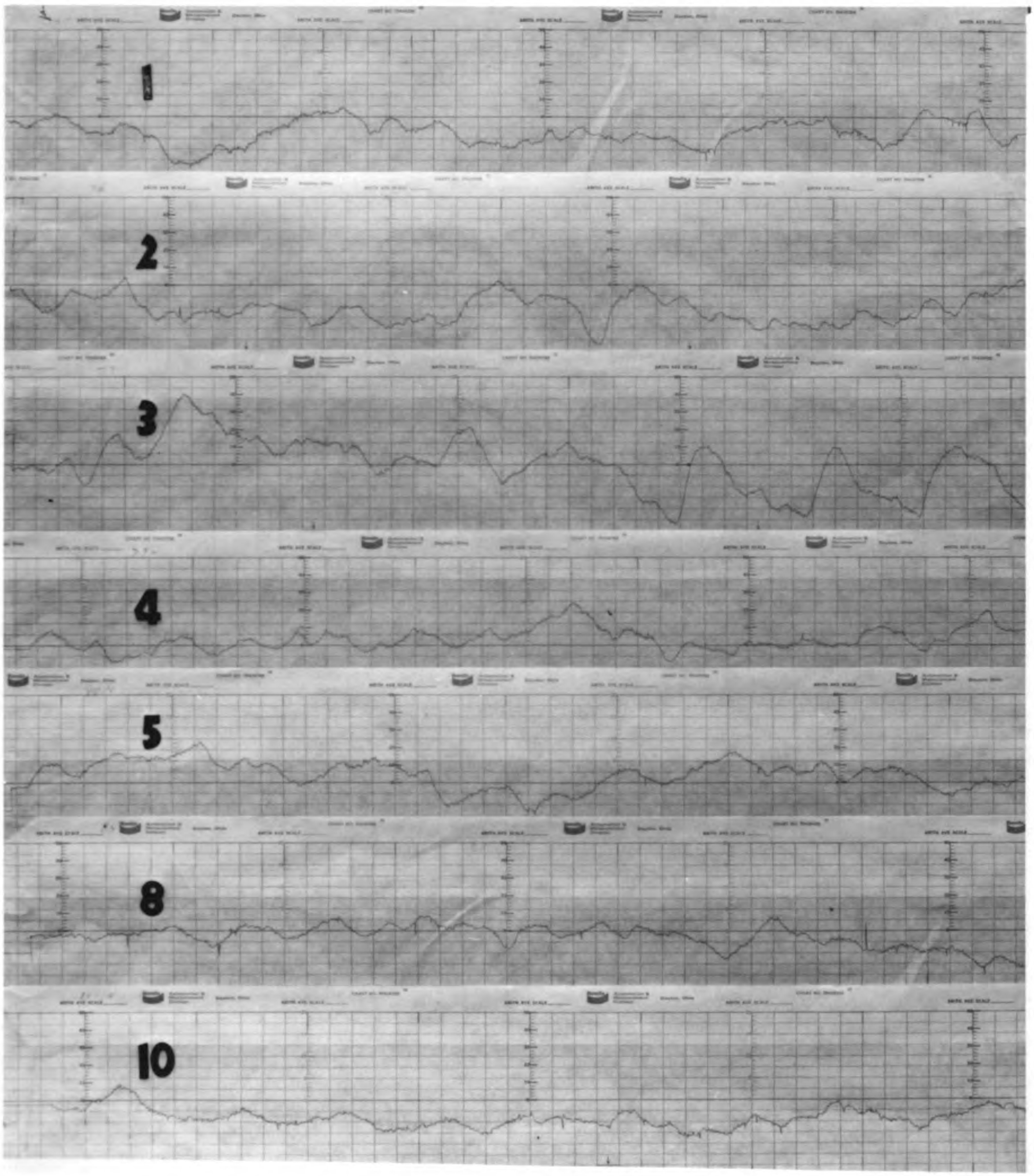


FIGURE 8. The original profiles of overlaid substrate with Bonding Sheet (group D) measured at condition 1.

FIGURE 8.

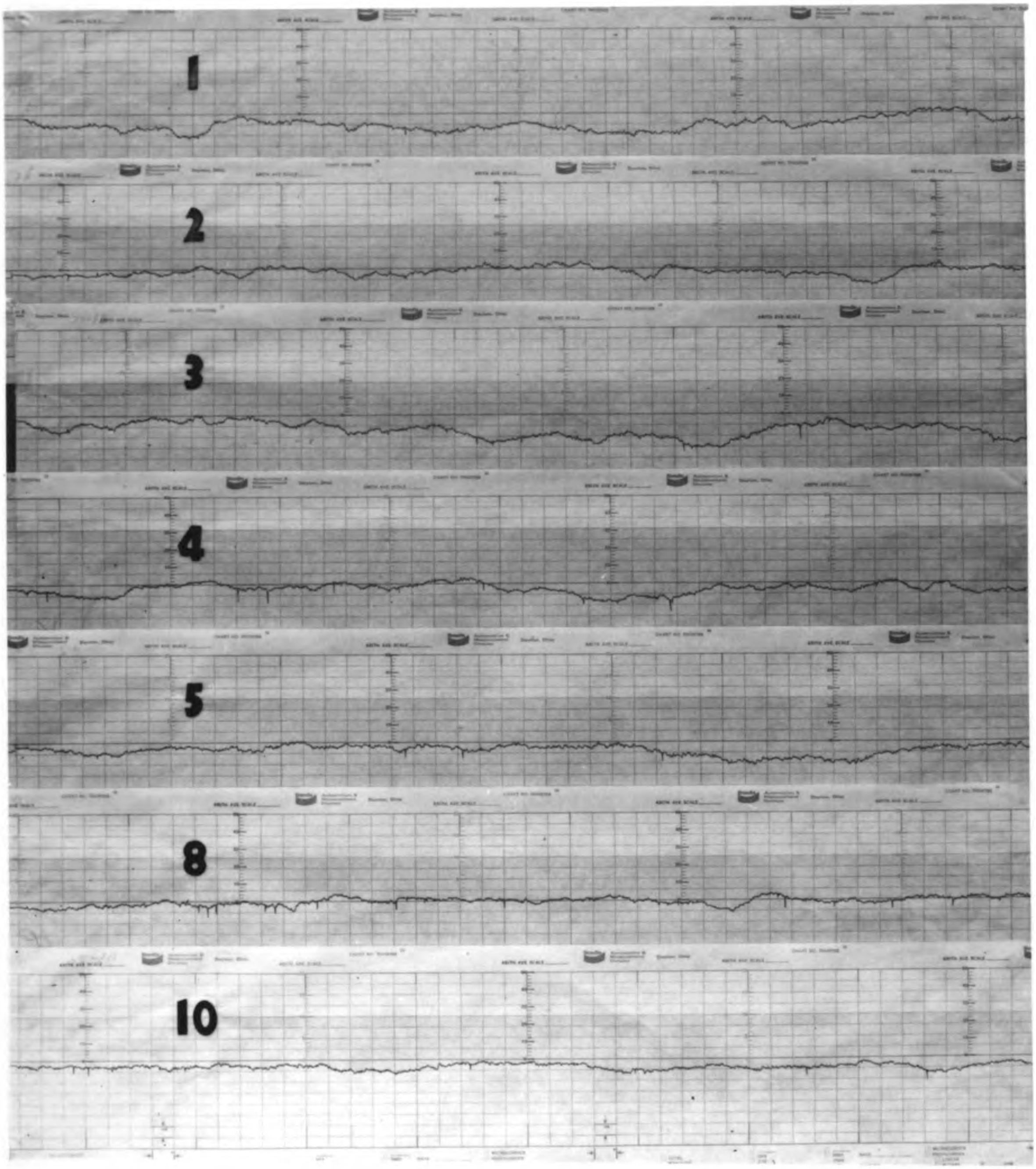


FIGURE 9. The original profiles of overlaid substrate with Bonding Sheet (group D) measured at condition 2.

FIGURE 9.

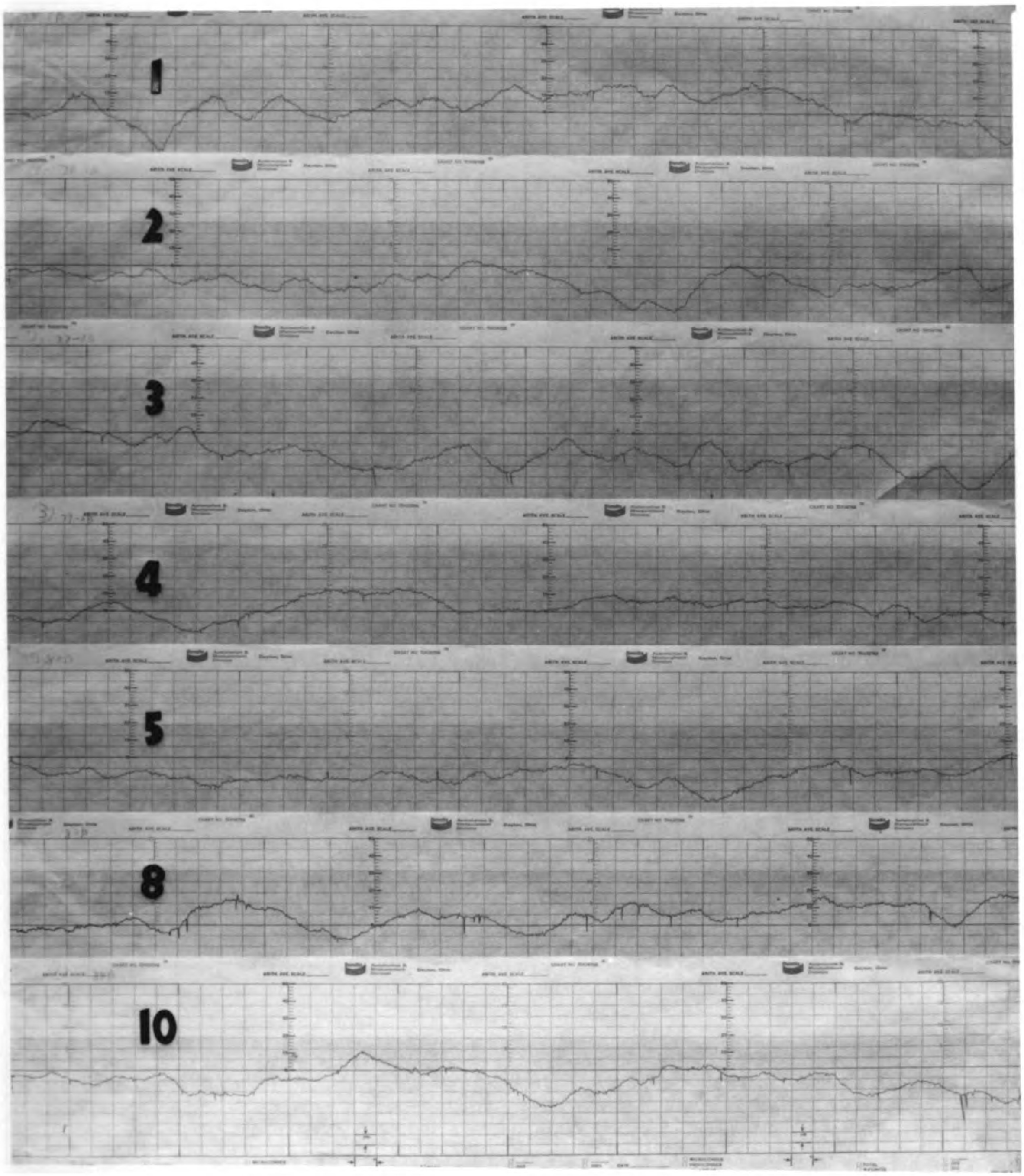
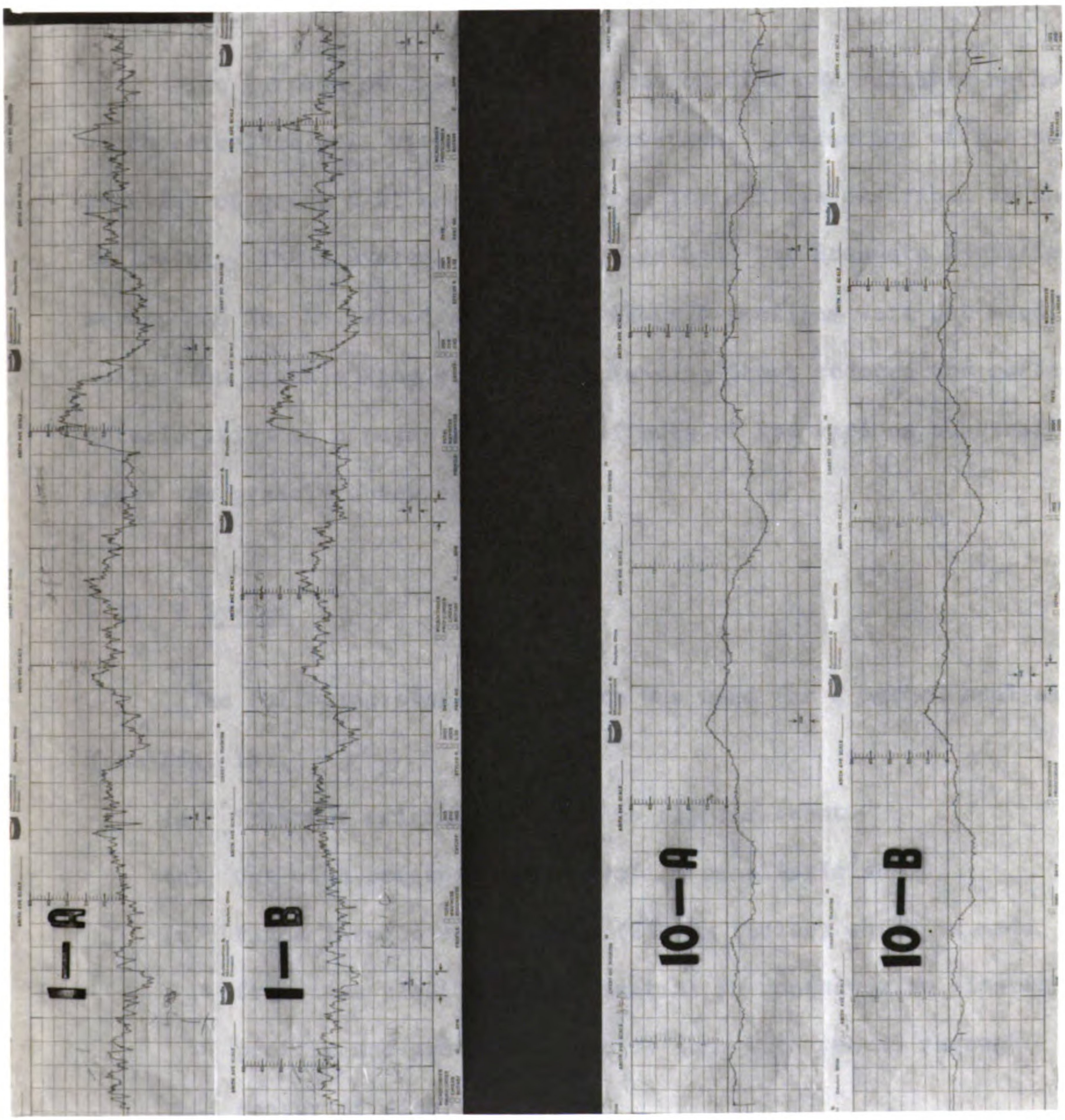


FIGURE 10. The reproducibility of the profiles produced from two traces over the same surface. I-A and I-B are plain substrate. 10-A and 10-B are overlaid substrate.

FIGURE 10.



CHAPTER 4

MATHEMATICAL EVALUATION OF SURFACE PROFILES

The purpose of this evaluation is to find out suitable methods which correlate well with visual observation. Evaluation of the surface profiles of group C at condition 2 (see Table 2) is described in the following. The E system, The Average method, The Standard Deviation method and The Lo method are used. Group D profiles were not used for evaluation at this time because the Bonding Sheet reduced the surface deterioration to a point where the effects of the various substrate types was greatly obscured.

4.1) E System

The following simple procedure was used for E method analysis (see Fig. 11).

(a) Transfer original profile to plastic sheet.

(b) Cut with scissors along profile on plastic sheet.

(c) Place large diameter disc (250 mm radius) which is made from same plastic sheet material in contact with plastic profile and generate curve of form with pencil through center of disc.

(d) Place small diameter plastic disc (25 mm radius) in contact with plastic profile and generate contacting envelope with pencil through center of disc.

FIGURE 11. The technique of evaluating E system. The radius of the large disc is 250 mm. The radius of the small disc is 25 mm. The length of the plastic profile is 23 inches.

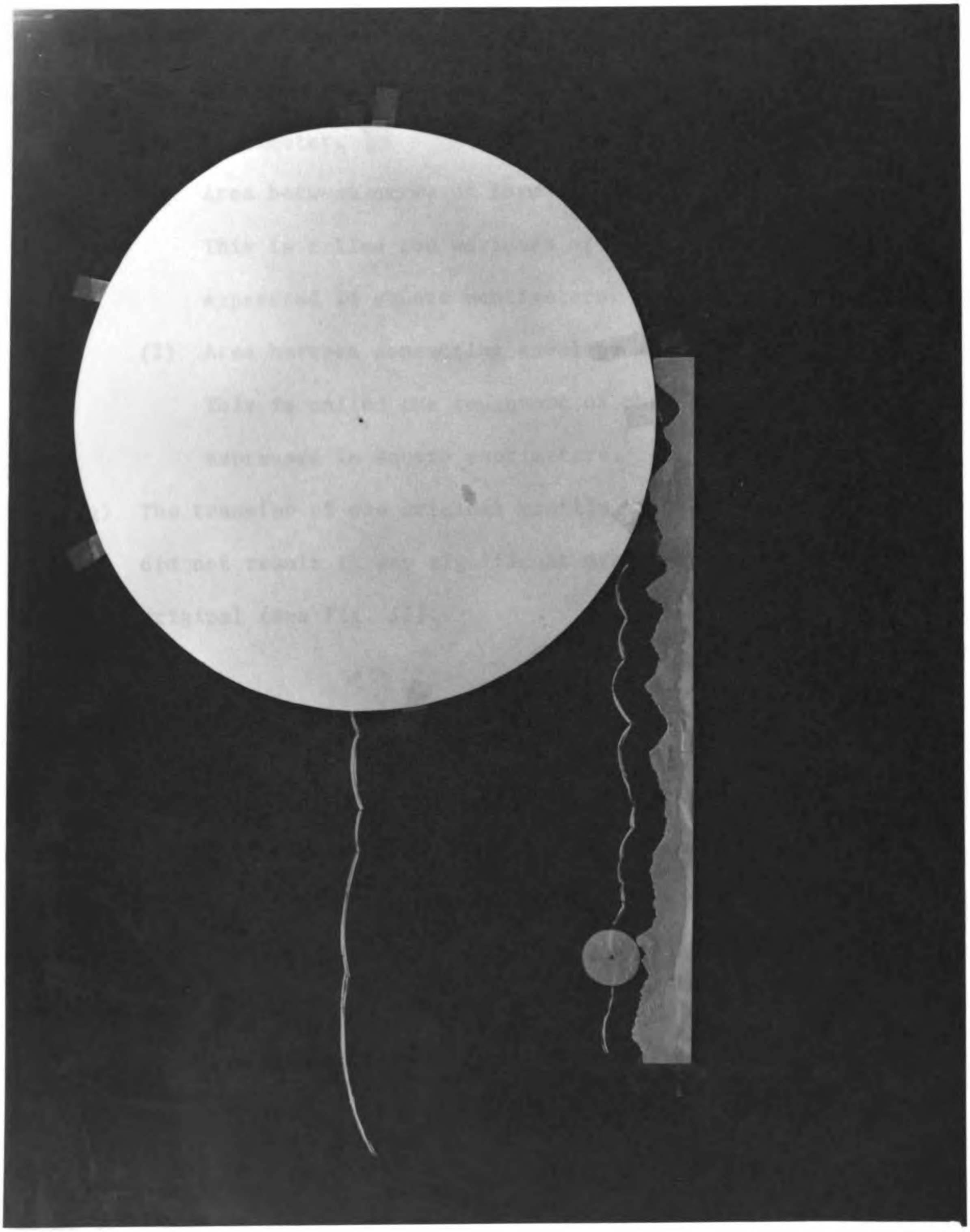


FIGURE 11.

(e) Move both generated curves downward without allowing any lateral slipping until they contact the plastic profile at at least two points.

(f) The following two areas are now defined and integrated with planimeter.

(1) Area between curve of form and contacting envelope. This is called the waviness of the surface and is expressed in square centimeters.

(2) Area between contacting envelope and plastic profile. This is called the roughness of the surface and is expressed in square centimeters.

(g) The transfer of the original profile to the plastic sheet did not result in any significant distortions of the original (see Fig. 12).

4.2) Average method

The principle of this method is to pick up points on the effective profile (original profile) at uniform intervals along the horizontal base. The vertical distance of these points from the average value of all points is each point's deviation. The area of deviation can thus be determined.

As shown in Fig. 13, the intersections between the numerous parallel vertical lines and the effective profile are the points called ordinates. The horizontal distance between vertical lines were chosen to be .5" based on the actual scale. The ordinates (Y values) were measured from an arbitrary base line (X axis). Forty-seven ordinates

FIGURE 12. Comparison of the original profile with the reproduced profile. I-A is the original profile. I-B is the profile reproduced from the plastic profile.

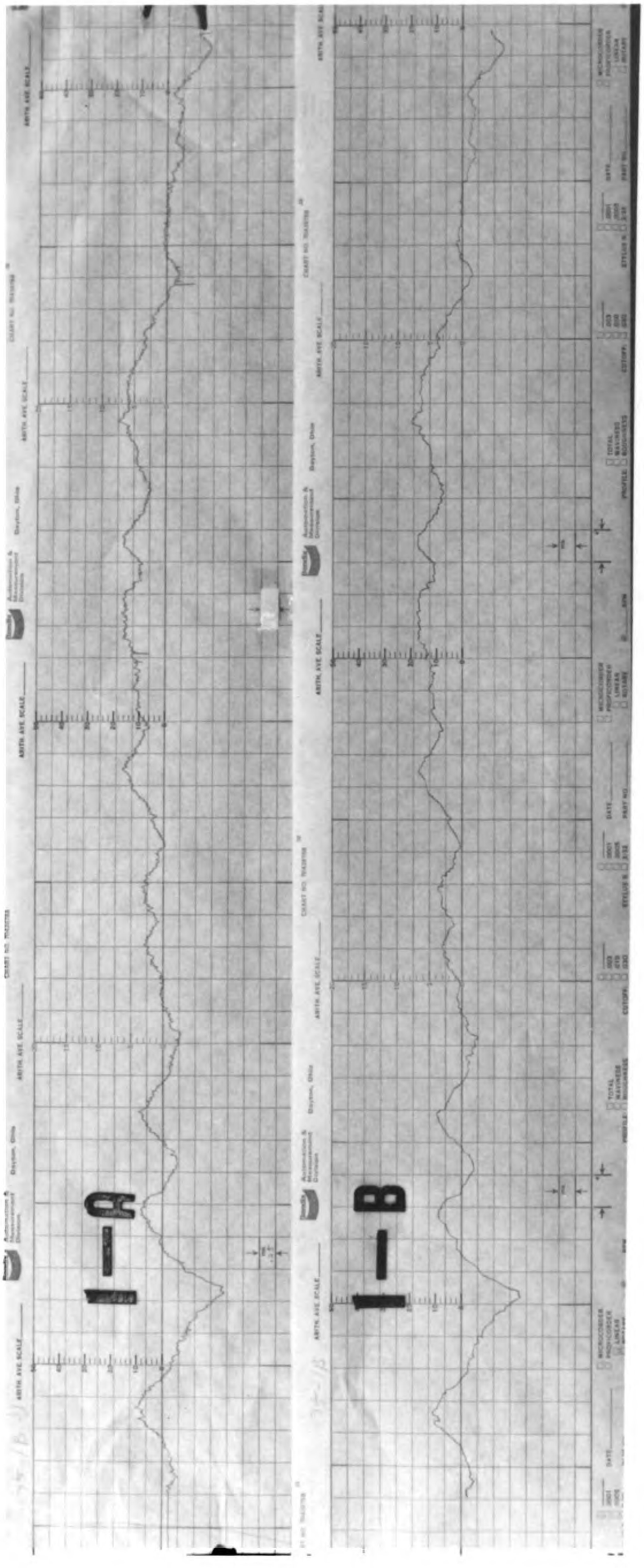
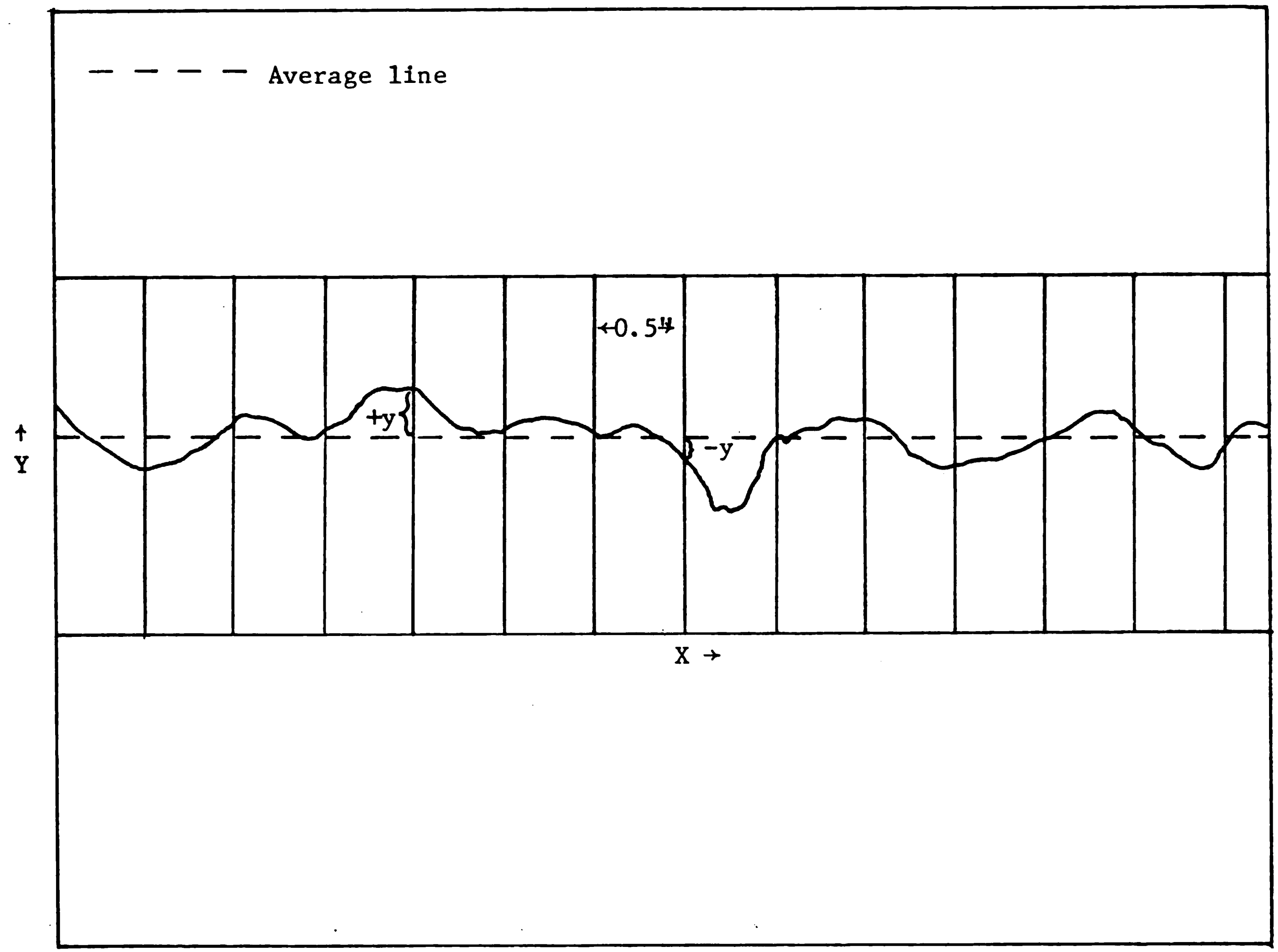


FIGURE 12.

FIGURE 13. Surface measures according to the Average method.

FIGURE 13.



were measured throughout the effective profile. The resulting y values were obtained by subtracting each ordinate value from the average value. The formula used to calculate the area is as following:

$$\text{Area (in}^2) = \frac{1}{\ell}\int_0^{\ell} |y| dx, \text{ where } dx = .5''$$

1: length of trace (approx. 3 in.)

The precision of this method depends upon the horizontal interval between points, the smaller the interval, the better the results.

4.3) Standard Deviation method

This method calculates the standard deviation of the ordinates described in the Average method instead of calculating the area deviation from the average.

4.4) Lo method

The former two methods, Average method and Standard Deviation method, use a straight line reference whereas the E method tries to exclude from analysis a certain acceptable trend line. The advantage of that technique was discussed earlier. The Lo method is another attempt to calculate the deviation of the profile from a non-linear compensating line rather than from a straight line.

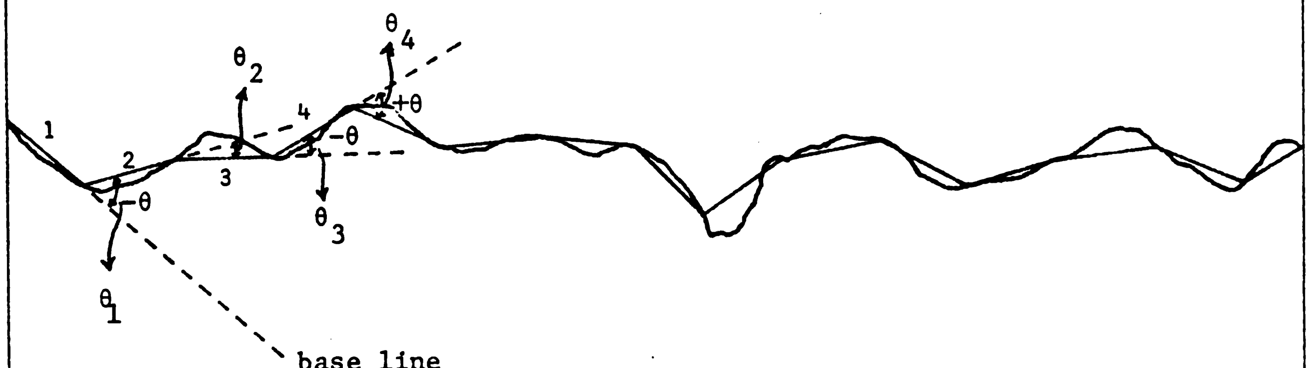
The idea of this method is to eliminate the effect of gross deviation to which the human eye is less sensitive. The means of removing gross deviation is to construct a mean line of compensation. The mean line is established by measuring uniform intervals along the profile with a divider (see Fig. 14). A straight mean line would result

FIGURE 14. Surface measures according to the Lo method.

FIGURE 14.

- - - - - Elongation line

.5" Roughness interval



$\theta_1' = \theta_1$

$\theta_2' = \theta_2 + \theta_1$

$\vdots$

$\theta'_n = \theta_n + \theta_{n-1}$

θ'_n: Roughness interval angle

θ_n: Actual measured angle

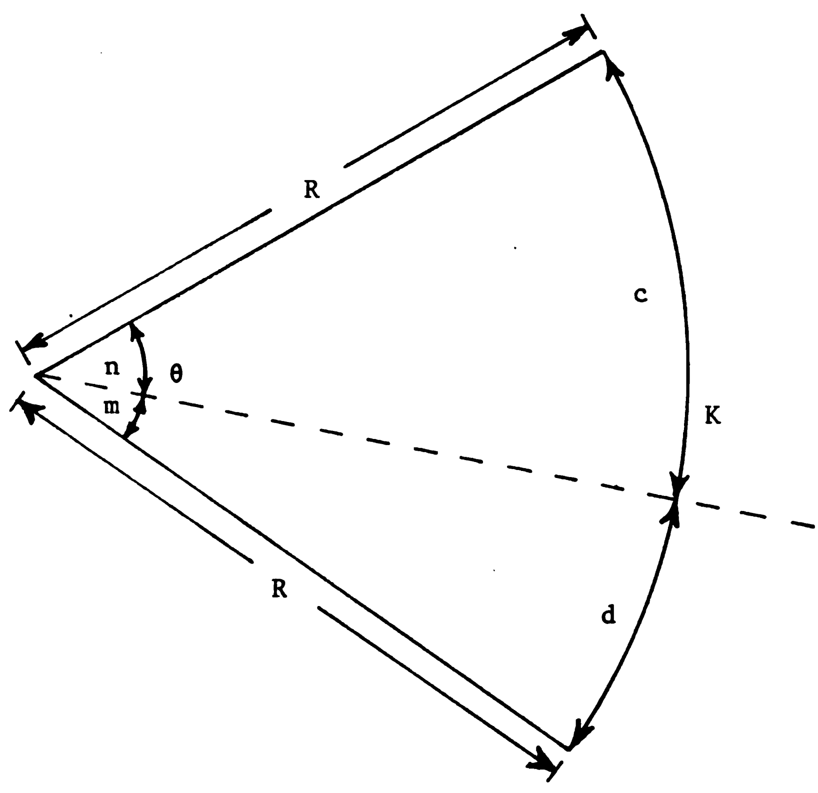
if the measured surface was flat. The mean line will take the form of a polygon in the case of a non-flat surface. The elements of the polygon are called Roughness Intervals. The length of the Roughness Interval is arbitrary. It should be selected to accent either the roughness or the gross deviation. The average amplitude and wave length of the profile are the factors to be considered when determining the Roughness Interval. In this study, intervals of .5" were marked out on the effective profile with a divider to fulfill this goal.

The trend of the mean line of compensation goes along with the profile curve. As the Roughness Interval becomes shorter and shorter and approaches zero, the mean line of compensation will coincide with the curve. The characteristic of the curve is thus described by two things, namely, the length of the mean line of compensation and the angle between the Roughness Intervals (the angle is measured between the n th. Roughness Interval and the elongation of the n-I th. Roughness Interval. The angle measured to the right of the elongation line is taken as positive, to the left of which is taken as negative). It is apparent that the longer the mean line and the larger the angle, the rougher the surface would be. In order to assess roughness, all the measured angles either positive or negative have to be changed to those angles based on the base line which is chosen to be the first Roughness Interval. Positive or negative angles being changed are on either side of the base line. As shown in Fig. 15, the average of the positive angles is m. The average of the negative angles is n. A segment of a circle relationship is established to combine the length of the mean line of compensation and the average angle between Roughness Intervals.

FIGURE 15. A segment of a circle relationship between the mean line of compensation and the average angle between roughness intervals.

FIGURE 15.

m: average of positive roughness interval angles
n: average of negative roughness interval angles
R: the length of the mean line of compensation
K: roughness factor



The length of the mean line of compensation which is R can simply be measured by adding up Roughness Intervals plus the last one which may equal to or less than one Roughness Interval. The roughness factor, K, can be calculated using the following formula:

$$K = \frac{\theta}{360^\circ} \cdot 2\pi R \text{ (in.)}, \; m + n = \theta, \; K = c + d$$

If $\frac{c}{d} >> I$ then the profile would have a generally concave character.

If $\frac{d}{c} >> I$ then the profile would have a generally convex character.

CHAPTER 5

STATISTICAL ANALYSIS AND DISCUSSION OF RESULTS

1. Results of the mathematical evaluation of surface profiles of group C specimen at condition 2 (see Table 2) are listed in Table 3 which includes the four evaluation methods described in the previous section.
2. A transformation of the results shown in Table 3 into qualitative rank is shown in Table 4. The ranking of the roughness and of the waviness according to the E system do not quite agree with each other. This may be due to the different sizes of the disc used to generate the so defined as roughness and waviness. The Average method and the Standard Deviation method have the same ranking. The E method (roughness) and the Lo method have the same ranking also.
3. The results of eight people's ranking by visual observation are listed in Table 5. The agreement of these eight ranks was tested by calculating Kendall's coefficient of agreement (5).

$$W = \frac{12\Sigma(\S - \bar{\S})^2}{K^2N\ (N^2-1)}$$

W: coefficient of agreement

K: number of observers

N: number of ranks

§: sum of rank numbers for each specimen

$\bar{\S}$: $\frac{(N+1)K}{2}$

TABLE 3. Results of Analysis by Several Methods of Surface Profiles of Group C Specimen Measured at Exposure Condition 2.

SPECIMEN	10N*	4N	8N	1N	2N	5N	3N	UNITS
AVERAGE METHOD	.414	.0472	.0555	.0590	.0674	.0674	.1233	in^2
STANDARD DEVIATION METHOD	.024	.208	.029	.031	.034	.035	.067	in
LO METHOD	1.524	1.873	1.617	2.118	2.923	2.681	4.036	in
E METHOD (Roughness)	16.4	21.6	16.5	21.8	27.1	22.0	54.1	cm^2
E METHOD (Waviness)	22.8	30.9	21.4	25.7	39.0	30.0	67.6	cm^2

N*: Overlaid substrate without Bonding Sheet.

TABLE 4. Qualitative Ranking of Surface Profiles of Group C Specimen Measured at Condition 2 Analysed by Several Methods.

SPECIMEN	10N	4N	8N	1N	2N	5N	3N
Average Method	1	2	3	4	5	6	7
Standard Deviation Method	1	2	3	4	5	6	7
Lo Method	1	3	2	4	6	5	7
E Method (Roughness)	1	3	2	4	6	5	7

*The smaller the number, the higher the ranking.

TABLE 5. Scores of Individual Specimens by Visual Judgement.

SPECIMEN NO.	10N	8N	5N	2N	1N	4N	3N
Rank	1	2	3	4	5	6	7
	1	2	3	6	4	5	7
	2	1	3	6	4	5	7
	1	2	3	6	4	5	7
	1	2	3	6	5	4	7
	1	2	4	6	3	5	7
	1	2	3	6	5	4	7
	1	2	5	6	4	3	7
Sun (§) =	9	15	27	46	34	37	56

*The smaller the number, the higher the rank.

In this test, K=8, N=7, $\bar{S}$=32, the coefficient was found to be .917. The significance of W was tested as follows:

$$F = \frac{(K-I)W}{I-W} = 77.34$$

$$n_1 = N-I-\frac{2}{K} = 5.75$$

$$n_2 = (K-I)n_1 = 40.25$$

According to the F Table, the test result is significant. This means that the ranking by the eight individuals can be considered to be in agreement.

The correlation between the visual observation and the various analytical evaluations was determined by using Spearman's formula (5).

$$r_s = I - 6\frac{\Sigma di^2}{N(N^2 - I)}$$

r_s: rank correlation coefficient

X_i: The rank of visual observation

Y_i: The rank of E method (or Lo method) or the rank of Average method (or standard Deviation method).

di: The difference between X_i and Y_i.

N : number of ranks

If N < 9, the significance of r is tested according to Table 6. Form $\Sigma(di)^2$, if smaller than A, the correlation is significant at the indicated level. In the test between the visual observation and the E system (or Lo method), r_s = .857, di = 8<16, the rank correlation is significient at the 95 percent level. In the test between the visual observation and the Average method (or the Standard Deviation

TABLE 6. Limit Values for Spearmen Rank Correlation Coefficient.

S \ N	4	5	6	7	8
95%	0	2	6	16	30
99%	-	0	2	6	14

A

method), r_s = .643, Σdi = 20>16, the rank correlation is not significant at the 95 percent level.

The test results show that the E system is rank correlated with the visual observation, as is the Lo method. The Average method and the Standard Deviation method are not correlated with the visual observation.

The conclusion is both the E system and the Lo method could be recommended for the evaluation of profiles of the type described in this article. The E method and the Lo method possess some similarities which were discussed separately in an earlier chapter. However, the Lo method would be preferable because of greater simplicity and would introduce less errors if the angles could be measured more precisely than using a simple device like a protractor.

4. Table 7 and Table 8 list the surface characteristics of group C and group D specimens at condition 1 and condition 2 (see Table 2) as determined separately by the E system and the Lo method. Fig. 16 and 17 and Fig. 18 and 19 are graphical illustration of Table 7. Fig. 20 and 21 are graphical illustration of Table 8. Surface quality may be indicated by the difference in roughness or waviness before and after exposure to severe moisture conditions. It is interesting to see from the graphs that both methods agree that the surface quality of melamine overlaid particleboard deteriorates much more severely at extreme exposure conditions when no bonding sheet is used.

   In other words, the bonding sheet has the ability to mask the surface instability of the substrate to a considerable extent. When no severe exposure conditions are encountered, the use of the bonding

TABLE 7. Surface Roughness and Waviness of Group C and D Specimen Measured at Condition 1 and 2 Analysed by the E Method.

SPECIMEN NUMBER	GROUP	CONDITION 1		CONDITION 2	
		Roughness (cm^2)	Waviness (cm^2)	Roughness (cm^2)	Waviness (cm^2)
10	C	9.6	11.3	16.4	22.8
	D	7.3	9.6	15.7	29.2
8	C	11.0	11.6	16.4	21.4
	D	8.0	11.1	15.8	26.6
4	C	13.1	17.6	21.6	30.9
	D	10.8	14.3	13.0	22.4
1	C	13.4	17.6	21.8	25.7
	D	11.6	15.2	20.0	26.6
5	C	12.5	12.3	22.0	30.0
	D	9.5	10.3	13.0	18.5
2	C	12.7	14.8	27.1	39.0
	D	10.2	14.7	14.0	26.3
3	C	14.4	15.5	54.1	67.6
	C	12.1	16.2	23.3	30.7

FIGURE 16. Surface roughness of overlaid substrate without Bonding Sheet (group C) evaluated at condition 1 and 2 by the E system.

FIGURE 16.

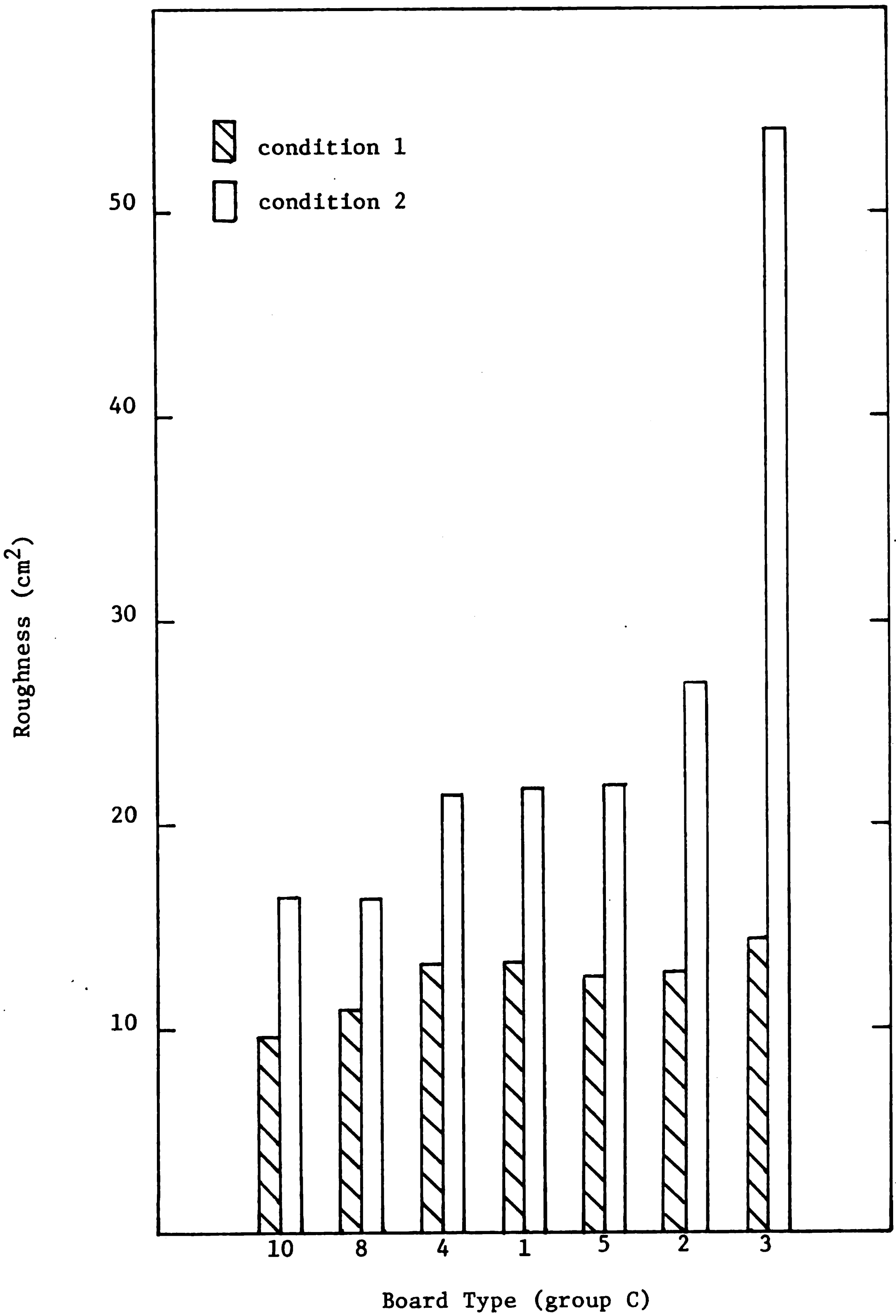

condition 1
condition 2
50
40
30
20
10
Roughness (cm^2)
10
8
4
1
5
2
3
Board Type (group C)

FIGURE 17. Surface roughness of overlaid substrate with Bonding Sheet (group D) evaluated at condition 1 and 2 by the E system.

FIGURE 17.

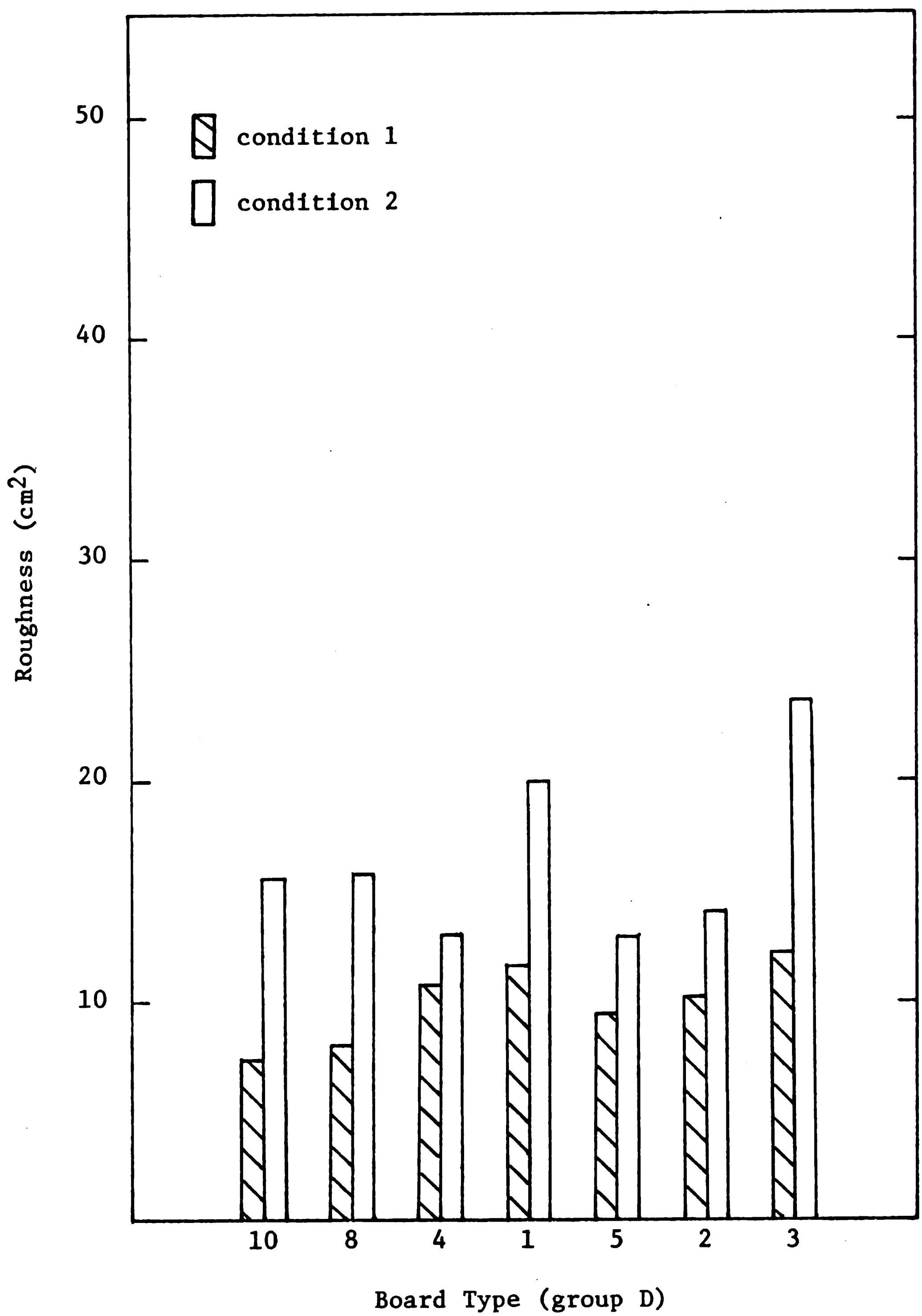

condition 1
condition 2
50
40
30
20
10
Roughness (cm^2)
10
8
4
1
5
2
3
Board Type (group D)

FIGURE 18. Surface waviness of overlaid substrate without Bonding Sheet (group C) evaluated at condition 1 and 2 by the E system.

FIGURE 18.

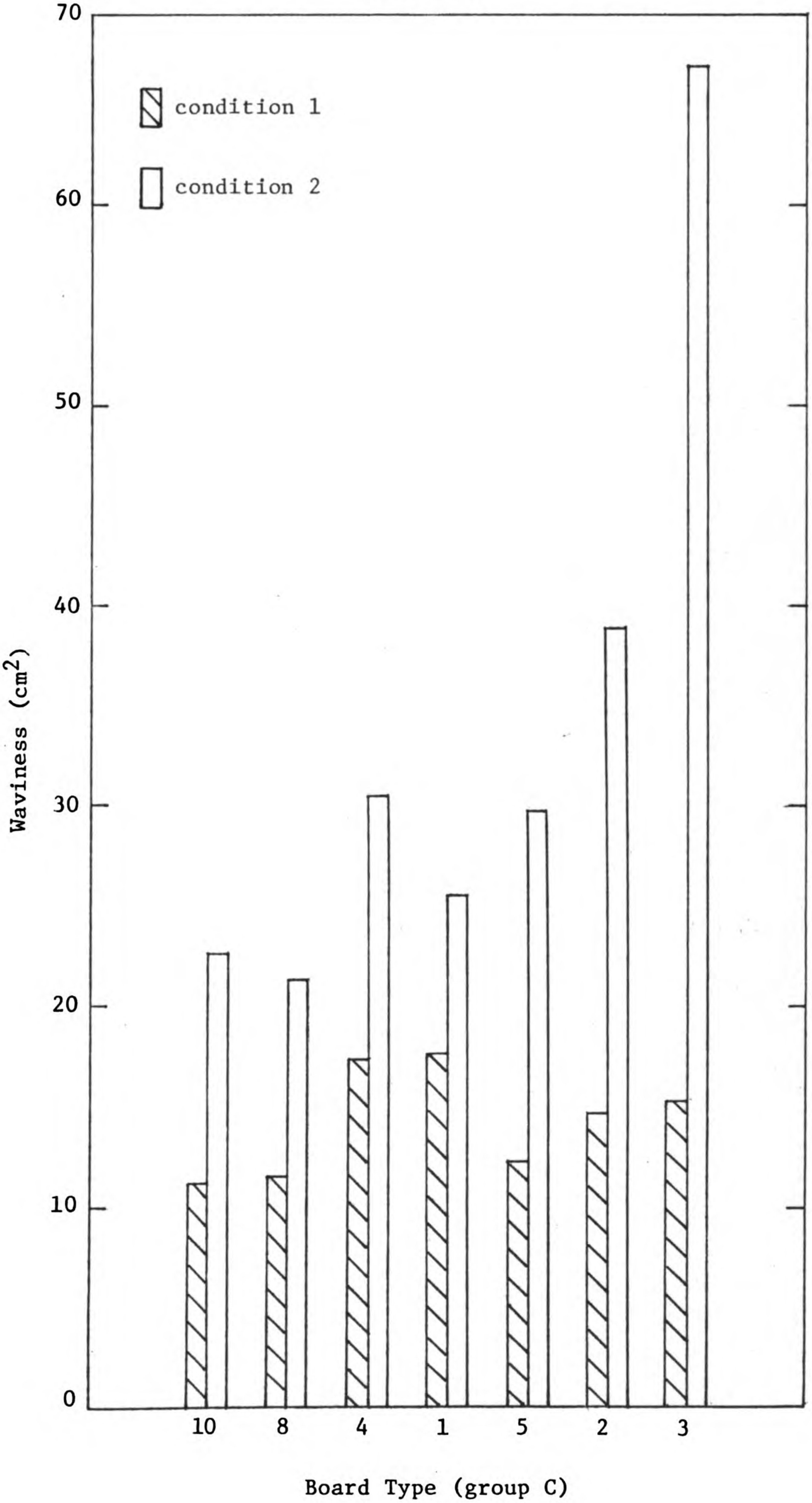

70
60
50
40
30
20
10
0
condition 1
condition 2
Waviness (cm^2)
10
8
4
1
5
2
3
Board Type (group C)

FIGURE 19. Surface waviness of overlaid substrate with Bonding Sheet (group D) evaluated at condition 1 and 2 by the E system.

FIGURE 19.

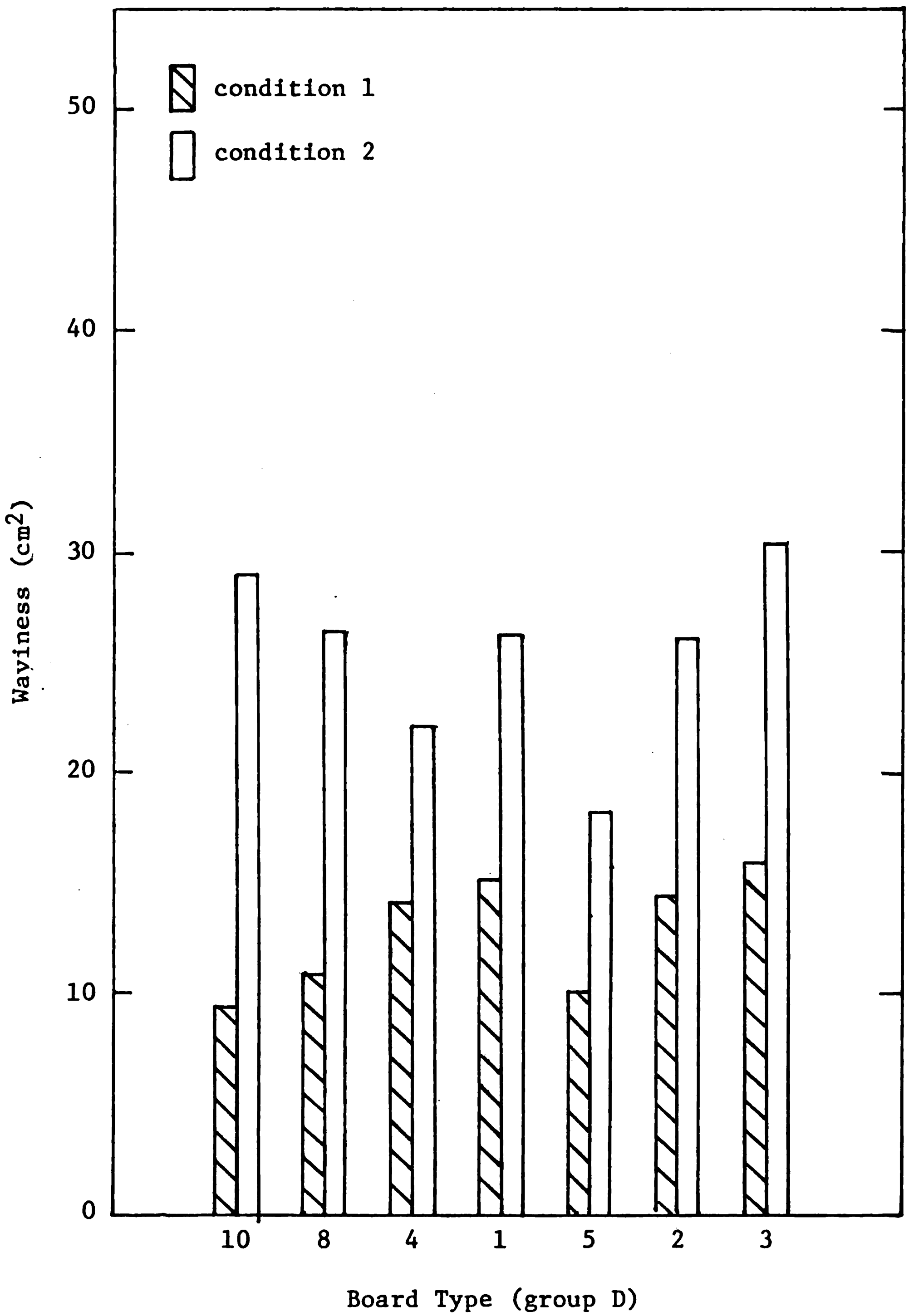

condition 1
condition 2
50
40
30
20
10
0
Waviness (cm^2)
10
8
4
1
5
2
3
Board Type (group D)

TABLE 8. Surface Roughness of Group C and D Specimens Measured at Condition 1 and 2 Analyzed by the Lo Method.

SPECIMEN NUMBER	GROUP	CONDITION 1	CONDITION 2
		Roughness (in.)	Roughness (in.)
10	C	1.087	1.524
	D	.588	1.444
8	C	1.016	1.617
	D	.662	1.546
4	C	.965	1.873
	D	.724	1.132
1	C	1.372	2.118
	D	1.554	1.823
5	C	.908	2.681
	D	.893	1.222
2	C	1.467	2.923
	D	.883	1.503
3	C	1.134	4.036
	D	1.195	2.390

FIGURE 20. Surface roughness of overlaid substrate without Bonding Sheet (group C) evaluated at condition 1 and 2 by the Lo system.

FIGURE 20.

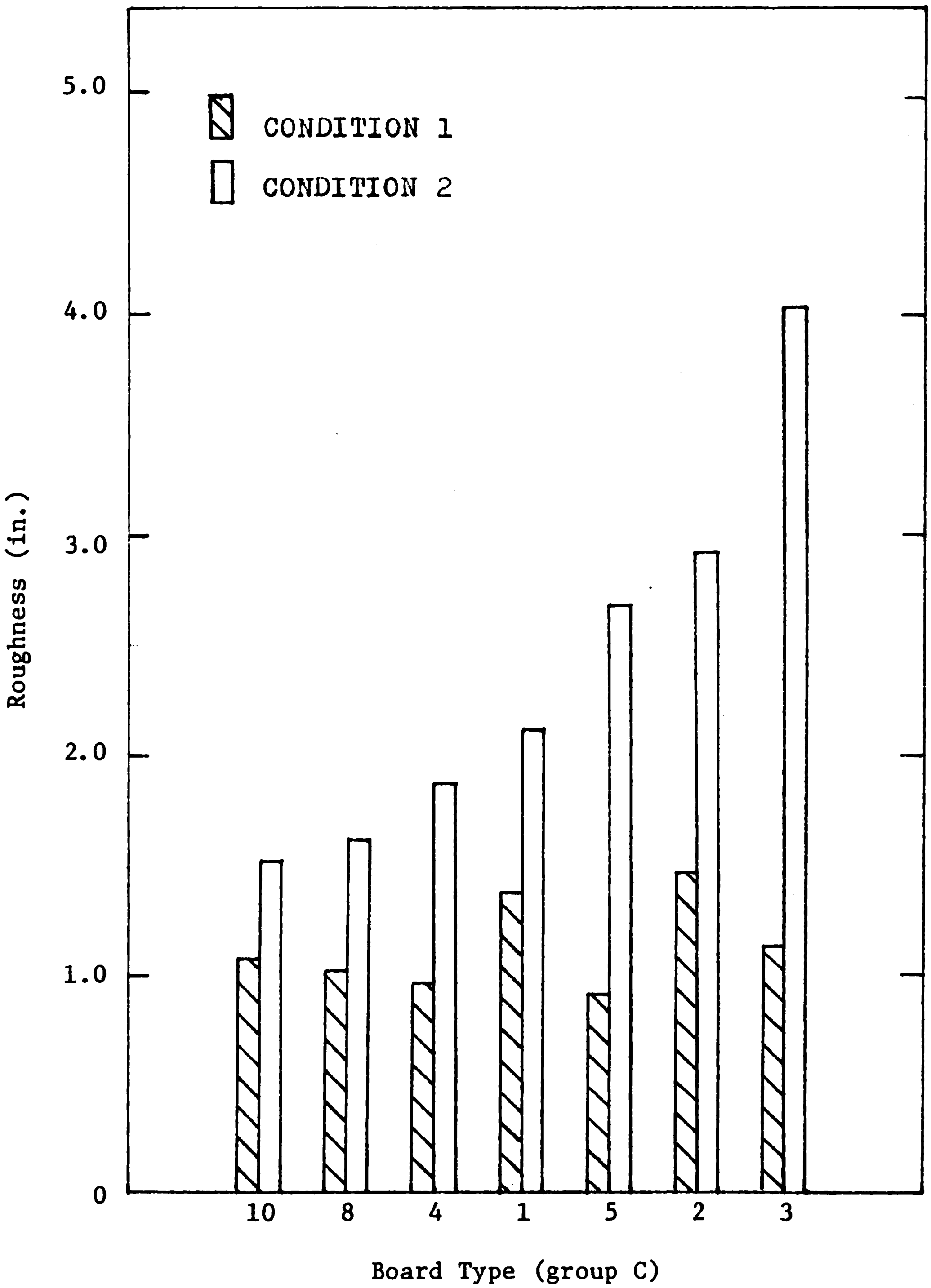
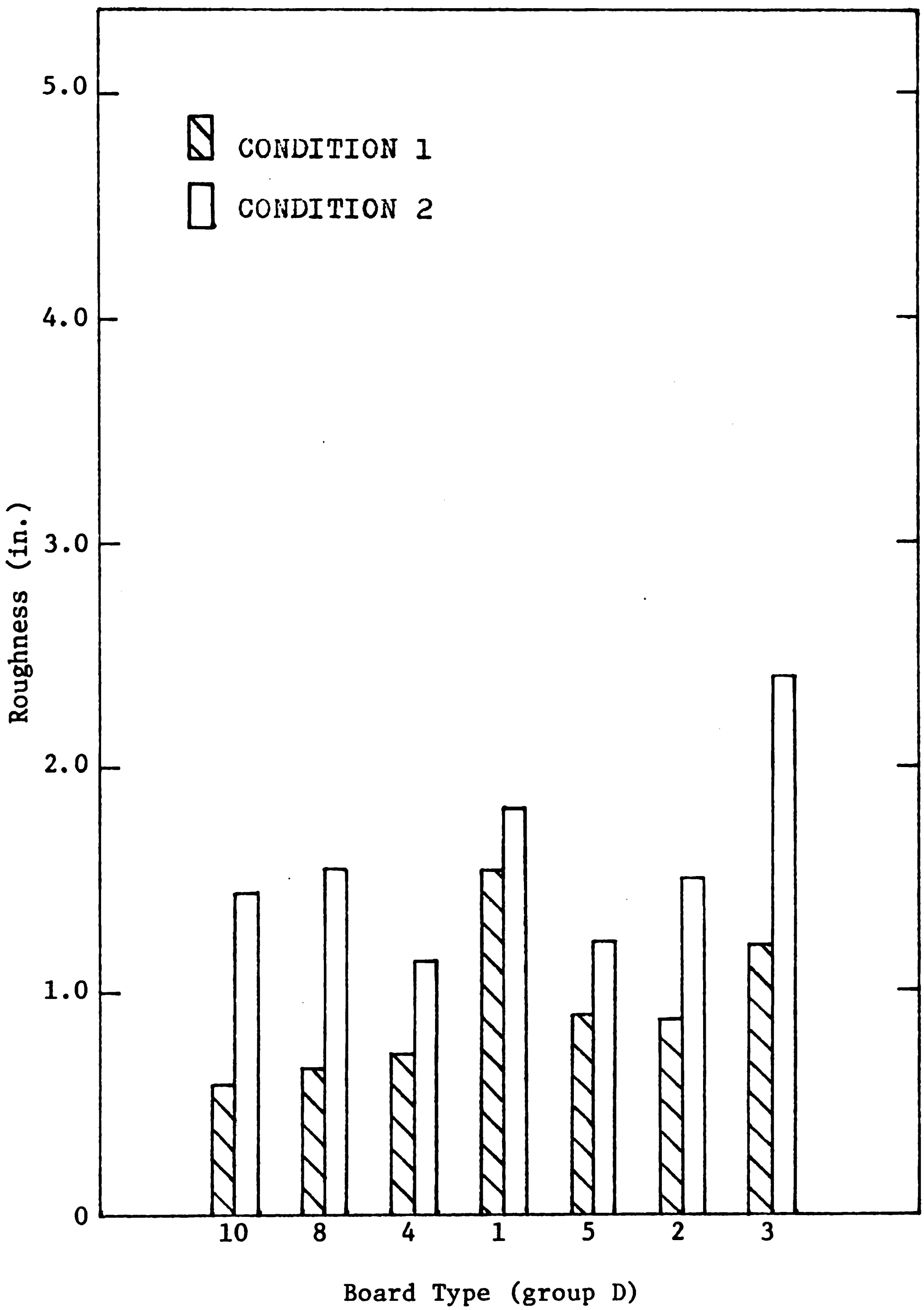

5.0
4.0
3.0
2.0
1.0
0
CONDITION 1
CONDITION 2
Roughness (in.)
10
8
4
1
5
2
3
Board Type (group C)

FIGURE 21. Surface roughness of overlaid substrate with Bonding Sheet (group D) evaluated at condition 1 and 2 by the Lo system.

FIGURE 21.


CONDITION 1
CONDITION 2
5.0
4.0
3.0
2.0
1.0
0
Roughness (in.)
10
8
4
1
5
2
3
Board Type (group D)

sheet is not justified. Under those conditions, substrates can be considered as having good surface quality. Comparing Fig. 16 with Fig. 17, Fig. 18 with Fig. 19 and Fig. 20 with Fig. 21, laminates 10, 8 and 1 do not gain much advantage by using bonding sheet under severe exposure conditions. It can therefore be concluded that substrates 10, 8 and 1 must have good surface quality. Surface quality is determined by several factors, one of them is the dimensional stability of the substrates. Due to the fact that substrate 1 is the only one not having been compressed down in thickness, it showed less thickness swelling (see Table 9, group A and B) and a better quality of the overlaid surface. Substrate 10 and 8 possess some other properties besides the dimensional stability, which make them deteriorate even less than substrate 1. Substrate 10 is fiberboard with fine surfaces. Substrate 8 has very fine particles on its surfaces.

5. Table 9 lists thickness, thickness swelling and water absorption of four groups of specimen exposed to condition 2. When comparing the thickness swelling of substrate having been compressed (group B) with those not having been compressed (group A), the former show a greater thickness swelling than the latter. This can be explained by internal failures occurring in the compressed particleboard. Substrate 1 and its laminates are the only exception. It had not been compressed significantly during the laminating operation and therefore the difference between group A and group B in thickness swelling is small. Table 9 also indicates that overlaid particleboards (group C and D) swell less than substrates (group B) and absorb less water. This could

TABLE 9. Thickness, Thickness Swelling, and Water Absorption of Four Groups of Specimen Exposed to Condition 2.

SPECIMEN	GROUPS	THICKNESS (in)	THICKNESS SWELLING (%)	MOISTURE ABSORPTION (%)
10	A	.744	9.0	10.49
	B	.640	17.0	10.56
	C	.610	13.6	8.00
	D	.673	11.0	9.26
8	A	.748	11.6	9.46
	B	.656	17.4	10.39
	C	.689	12.8	8.46
	D	.673	13.7	9.56
4	A	.755	15.9	10.73
	B	.591	25.0	11.25
	C	.600	20.2	8.53
	D	.628	16.1	8.40
1	A	.757	9.6	8.46
	B	.736	10.3	9.15
	C	.770	6.1	6.90
	D	.785	4.3	6.15
5	A	.754	15.4	11.51
	B	.654	22.8	11.98
	C	.685	15.5	9.18
	D	.681	15.9	9.36
2	A	.744	11.8	9.23
	B	.581	27.0	11.81
	C	.614	16.8	8.51
	D	.644	15.2	8.17
3	A	.746	15.5	10.64
	B	.669	23.0	12.04
	C	.665	19.4	9.25
	D	.717	13.1	8.58

be explained by the reduced water permeability of the overlaid boards and by some swelling restraint caused by the overlays.

6. General properties of the seven types of commercial particleboard are listed in Table 1 (18).

CHAPTER 6

CONCLUSION

The melamine impregnated paper can improve the surface quality of the substrate by restraining the thickness swelling, masking imperfections and providing a smooth surface. On the other hand the overlay accentuates small imperfections because of its high gloss.

Both the E system and the Lo method are used in this test to evaluate effective profiles of melamine overlaid particleboard, because both have good correlation with visual observation which is considered a good indicator of surface quality. The E system provides a clear separation of roughness, waviness and error of form, while the Lo method eliminates the effect of gross deviation by constructing a non-linear compensating line. The determination of the radii of the discs in the E system and the length of the roughness interval in the Lo method should be studied further.

The results of the evaluation based on the E system and the Lo method reveal that surface characteristics of overlaid board are greatly affected by the substrate. Those laminates with bonding sheet have better surface quality than those without bonding sheet only under severe moisture conditions. Substrates with good surface quality need no bonding sheet to add to the cost instead of improving surface quality. Under this interpretation, substrate 10, 8 and 1 are considered as having good surface quality.

The melamine overlay can only be applied to substrates having densities higher than 45 pounds. Otherwise, the long press cycle will cause compression of the substrate resulting in internal failures, and excessive thickness swelling.

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