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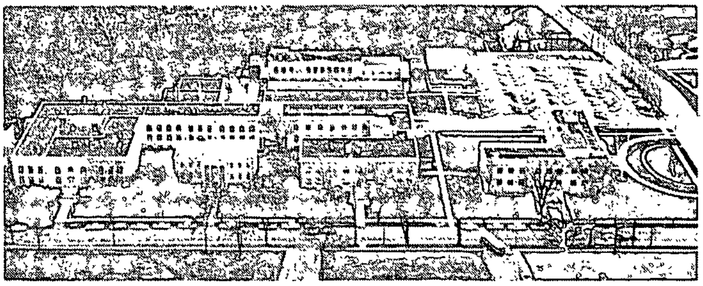

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

DEVELOPMENT OF A COLD CORRUGATING PROCESS

CONTRACT NO. DE-AC02-79CS40211

TECHNICAL PROGRESS REPORT TWO

TO THE

U. S. DEPARTMENT OF ENERGY

DECEMBER 15, 1981

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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INTRODUCTION

Research and development work on a cold corrugating process has been underway at The Institute of Paper Chemistry (IPC) for several years. This early work has proceeded through laboratory concept work, laboratory feasibility, pilot trials, and process optimization to the last stage--that being commercial evaluation and demonstration of a cold corrugating system. Financially, the project was supported in the early exploratory phases by the Institute; then by the Fourdrinier Kraft Board Group (FKBG) of the American Paper Institute through the laboratory feasibility studies; and in recent work on process development, pilot trials, and process optimization, funding has been provided jointly by the IPC and FKBG. Although process development work is continuing, the process has been developed to the point where commercial implementation and evaluation is realistic. To accomplish this goal, it is necessary to provide a first prototype cold corrugator in a box plant for use in commercial production. This large task, combined with the process work, is being carried out as a cooperative project under the combined sponsorship of the IPC, FKBG, and the U. S. Department of Energy (DOE). The Union Camp Corporation (UCC) has been contracted by the IPC to provide the host site for the commercial cold corrugator.

To document the early process development work three progress reports (1-3) have been issued. In Compliance with DOE reporting requirements the first technical progress report (4) was issued November 7, 1980. As the first in a series, the technical progress report reviewed, in some detail, all of the process development work, the plans and specifications for the commercial evaluation equipment, and an economic analysis for cold corrugating. The purpose of this second technical progress report is to review developments that have occurred since the date of the last report.

This report is presented in two parts: Part A covers recent work on cold forming and on adhesive development; Part B describes the actual designs of the commercial evaluation equipment and reports on operating experience to-date.

PART A — THE COLD CORRUGATING PROCESS

INTRODUCTION

The corrugating process, whether hot or cold, has two main process elements; forming or fluting of the corrugating medium, and bonding of the medium to the liners. There are two bonding processes; medium to single-face liner, and medium to double-face liner. The single-face bonding operation involves short durations and high pressures. The double-face bonding operation involves longer durations and low pressures. Successful cold corrugating requires that the forming and bonding operations be accomplished without heating of the paperboard components. The research discussed in this first section is concerned with fundamental aspects of the forming operation; a later section will discuss research on the double-face bonding process.

COLD FORMING

Introduction

In its simplest concept, corrugating is a forming operation. The medium is drawn under tension into the nip between the corrugating rolls, termed the labyrinth. In the labyrinth the medium is bent to the flute contour under the prevailing stress, temperature, and moisture conditions. At the center of the labyrinth high transverse compressive forces are applied to the medium which serve to "set" the fluted shape. Thus high tensile, compressive and shear stresses are induced in the medium as it is formed. These stresses affect combined board quality and can cause flute fracture or excessive high-lows during the corrugating operation.

Historically corrugating has been carried out with the corrugating rolls heated to high temperatures of about 350°F (hot process). The high temperatures were believed to be necessary for proper flute formation at high speeds. They also serve to "set" the adhesive.

However, our work has shown that commercial mediums can be corrugated satisfactorily under "cold" conditions, i.e., with the corrugating rolls at room temperature (cold process). The cold process reduces both energy and capital requirements.

Most of the properties of the cold formed board are comparable to those of hot formed board. However, we have found that some mediums exhibit lower flat crush strength when cold formed although the very important initial portions of the flat crush load-deflection curves are comparable.

To enable forming under cold conditions much development work was carried out in the early stages of the program. The development work was based on our understanding of the hot corrugating process but mainly involved the empirical and experimental development of ways to cold form the medium at commercial speeds. In a successful forming process, the medium must exhibit good runnability. This is usually exemplified by the absence of flute fracture over the commercial speed range, acceptable flute formation, good release between the corrugated medium and the corrugating rolls to avoid the build-up of debris or picking in the rolls, and acceptable structural properties of the single-face web.

The empirical development work summarized in Technical Progress Report One (4) showed that satisfactory cold forming could be achieved in various ways. Factors which tend to improve cold forming include:

1. The use of corrugating rolls with the lowest possible friction coefficient.
2. Avoiding wrap of the top corrugating roll by the medium.

3. Prefeeding the medium directly into the forming nip under the lowest workable tension.
4. Using the smallest practical roll diameter.
5. Pretreating the medium with a friction reducing agent - low melting point wax being a good example.
6. Running mediums with a higher than normal moisture content - 7-8% being a good target.

As indicated by items 1-5 minimizing the tensions induced in the medium is essential to good runnability. The tension magnitudes are greatly affected by the coefficient of friction of the medium as it is drawn into the labyrinth. For mediums having high friction coefficients (above about 0.4-0.5) medium treatment agents are usually necessary to achieve good runnability under cold conditions. However, our work shows that mediums having friction coefficients less than about 0.4 (about half of all mediums tested) can be successfully cold formed at commercial speeds without any form of pretreatment.

While the above experimental work has promoted development of the cold process, fundamental work on the fluting process shows great potential for improving performance and the utilization of fiber. The basic relationships between medium properties and forming performance have not been well-defined, even in the case of hot corrugating, and this lack is even more evident in cold corrugating. There is evidence that medium properties can be optimized with respect to cold forming; however, we believe this can best be accomplished by basic studies of the forming process. When we can define the medium properties required for good formability and structural performance we can modify the manufacturing process at the corrugating medium mill to produce mediums with the optimum balance of properties.

Knowledge gained from fundamental research on cold forming will have immediate application as the cold process is implemented by various box plants.

However, it should also have applications to the hot process. There are about 600-700 converting plants with corrugators. After demonstration of the full-scale feasibility of the cold process it will take some years before the industry can utilize its capital and other resources to change most corrugators to the cold process. We believe there will be a transition period of some years during which both cold and hot processes are employed in the industry. Thus while our work is directed to optimizing the medium for cold forming it can also be used to improve the industry's use of fiber and energy in the hot process.

Accordingly the overall objective of this research is to analyze the corrugating forming process to determine the characteristics which optimize the structural performance of the board and maintain or improve runnability under cold forming conditions. This includes consideration of hot forming where appropriate to basic understanding. Therefore, initial emphasis was placed on determining how medium and board performance is affected by cold and hot fluting. However, our results show that the losses incurred in both fluting processes are much more important than the differences between hot and cold fluting. Hence these losses, rather than the differences between hot and cold forming are the primary target of our research.

In this first phase of a continuing project we have directed attention to the effects of forming conditions, forming geometry and flat crush behavior.

Background

Most of the published work on the corrugating process is concerned with hot corrugating. However, many of the forming phenomena are similar in hot and cold forming. Therefore the forming concepts discussed below draw heavily on the hot corrugating literature but care has been taken to make distinctions between hot and cold forming as seem appropriate.

In general, corrugating performance under either cold or hot fluting conditions is limited by several factors which affect board quality. They include flute fractures or damage, high-lows and adhesion. For example, under hot conditions fractured flutes lower the quality of the board as noted by McKee and Gander (5). They reported losses in flat crush ranging up to 13% and losses in edgewise compressive strength of up to 20%. Similar losses can occur under cold conditions. Usually the strength falls off gradually with increasing speed because only sporadic fractures are initially encountered as noted by Gottsching and Otto (6) in their work on the hot process. However, the presence of fractures is usually marked by an increase in flat crush variability. Thus the corrugating process imposes high stresses in the medium which can lower board quality if they exceed the "strength" of the medium. Even though fracture does not occur, the stresses during fluting reduce the strength of the fluted medium. These effects of the fluting stresses are the subject of this work.

Forming Stresses

At the entrance to the labyrinth (See Fig. A1) the main stress on the medium is due to the applied brake tension. The tensile stress at A is approximately constant across the medium thickness. The web tension in the medium is one of the most important factors affecting runnability and board quality. Many investigators have shown that, for the hot process, increasing web tension lowers the speed at which fracturing occurs (5-8). Our work has shown that increasing web tension has similar effects in cold corrugating (4).

In the labyrinth (Regions A to C, Fig. A1) the medium must travel faster than the tips on the corrugating rolls to accommodate the take-up or draw. As a result there is a frictional drag on the medium. The drag progressively increases

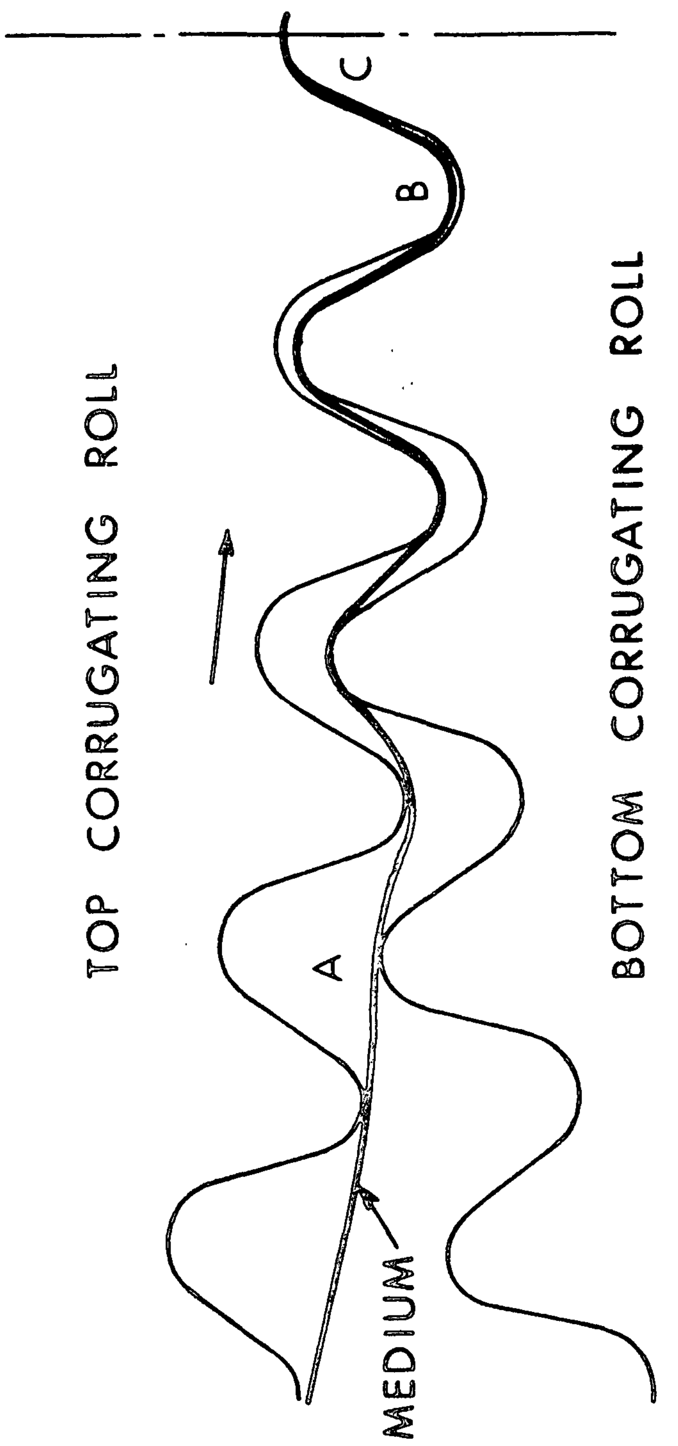


Figure A1. Labyrinth Corrugating Rolls

the web tension as the medium moves toward the center of the forming nip. McKee and Gander (5,9) showed that the web tension near the center of the labyrinth is much greater than the initial or brake tension. Figure A2 shows that the web tension in the final stages of forming is strongly dependent on the coefficient of friction, μ, between the medium and the corrugating rolls. Recently, Thomas (10) obtained similar results in an analysis of the C-flute labyrinth (Fig. A3).

Figure A3 shows that increasing the coefficient of friction between the medium and corrugating roll surfaces from 0.2 to 0.3 will cause a 100% or more increase in the final tension in the medium. For this reason the application of a small amount of certain "slip" agents to the medium or corrugating roll will reduce the tension in the medium during forming. Markedly higher corrugating speeds can be achieved using such agents. The effectiveness of various agents under "hot" corrugating conditions is discussed in Ref. 11. "Slip" agents also reduce the tendency to form high-lows under hot conditions (11,12).

Under cold corrugating conditions we have found that many mediums must be treated with friction reducing agents to prevent fracture and minimize high-lows (13-15). The coefficient of friction of corrugating medium is often much higher at room temperature than under hot corrugating conditions. In such cases flute fracture can occur unless suitable agents are used. In the previous report (4) we summarized the results of experimental corrugating trials on 35 commercial mediums. The mediums were evaluated to determine runnability and board quality both with and without application of medium treatment agents. All mediums were successfully cold formed at commercial speeds and web tensions by using treatment agents; those mediums with friction coefficients below about 0.4 (about half of all mediums tested) were successfully cold formed at commercial speeds without treatment agents. Our results also indicate that the effectiveness of various

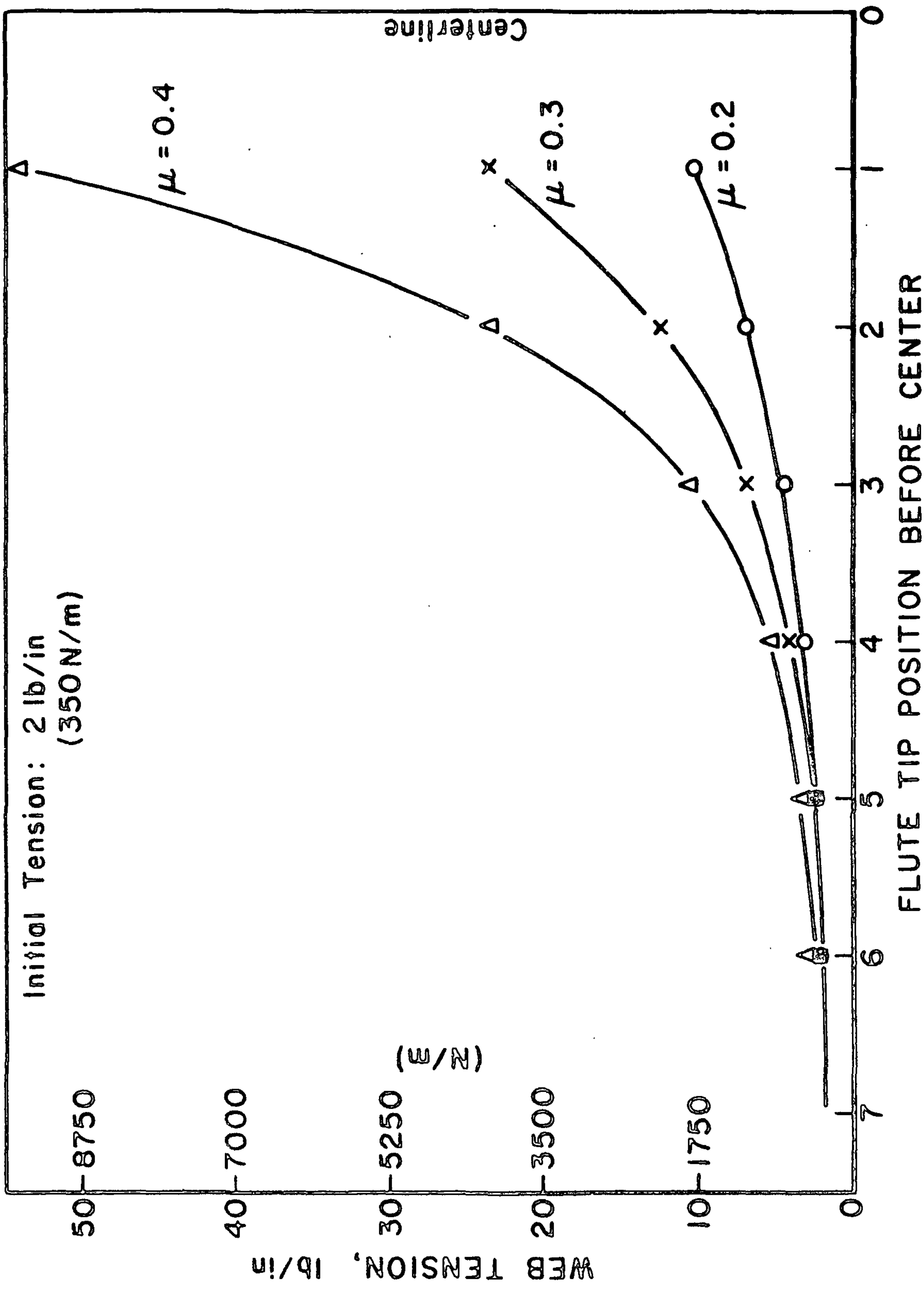


Figure A2. Effect of Friction on Web Tensions in the Corrugating Labyrinth (μ = Coefficient of Friction) (From Ref. 9)

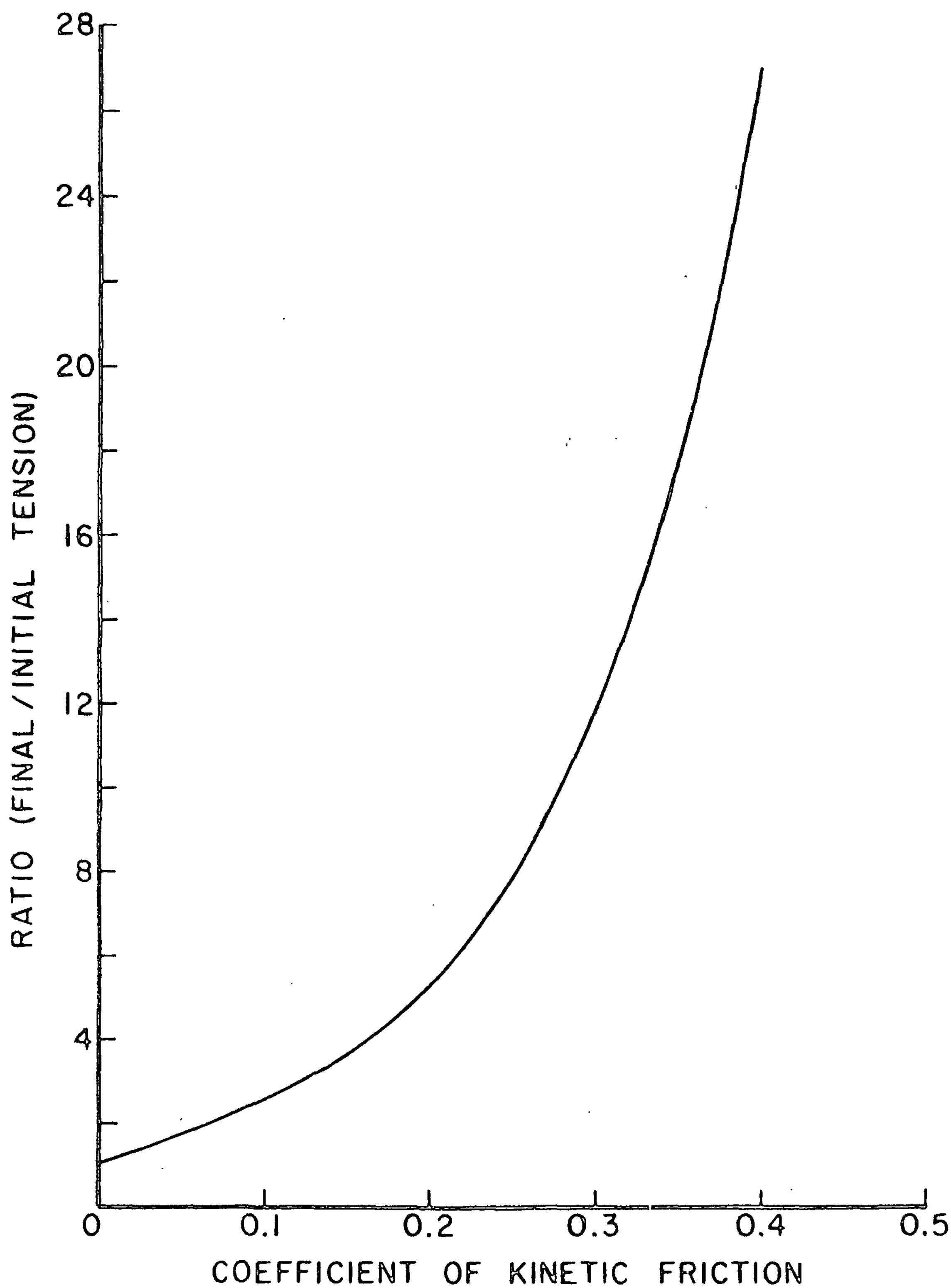


Figure A3. Maximum Web Tension in Labyrinth for a C-Flute Contour (From Ref. 10) slip agents and hence the choice of a proper agent varies with the corrugating temperature condition (13).

The medium at the flute tips is bent to the tooth radius giving rise to tensile stresses on the outside and compressive stresses on the inside (Fig. A4B). When added to the transport tensions (Fig. A4A), the stress on the outside convex surface is increased as illustrated in Fig. A4C. A critical state of stress may be reached when the transport and bending stresses are added and hence cause tip fracture. The bending stresses and strains will depend on the medium caliper and radius of curvature of the corrugating roll flute tip. The higher the caliper or the smaller the radius, the greater the strain and hence likelihood of fracture.

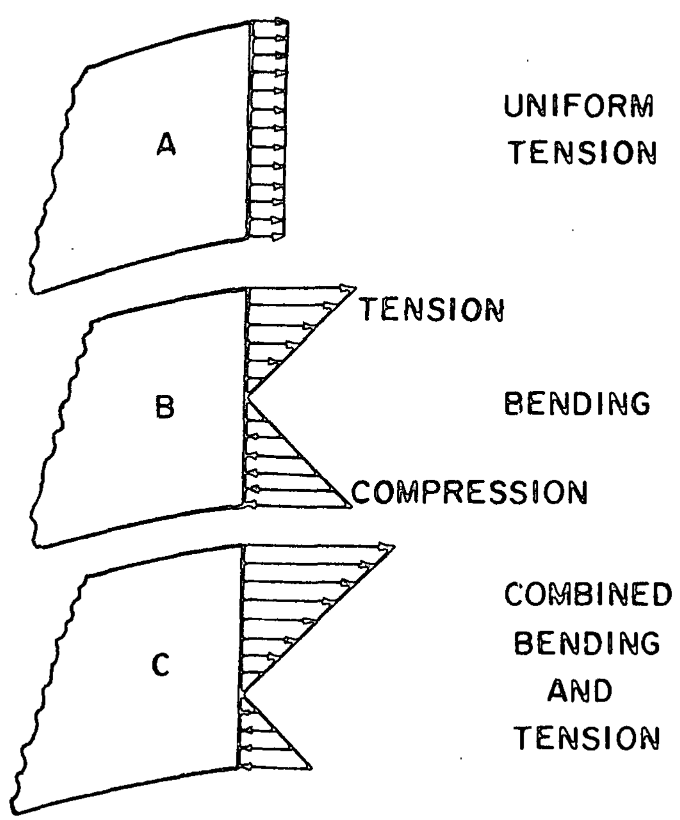


Figure A4. Combined Bending and Web (Uniform) Tension (Ref. 9)

Estimates of bending strain on the flute tip are greater than the allowable machine direction stretch of medium (5,10); however, shear stresses induced in the medium during forming reduce the net bending strain to permit forming without fracture. The transverse shear modulus of medium is quite low compared to the in-plane moduli thus permitting high shear strain levels at low shear stress levels. This is due to the "layered" nature of most paperboards. The shear strains generated in the medium will reduce the intensity of the bending strains and assist in the forming. As an extreme example some mediums delaminate during hot corrugating due to excessively high shear strains; the same may occur under cold conditions although it has not been observed in the mediums tested to this time.

At the center of the labyrinth, point C in Fig. A1, high transverse compressive forces are applied to the medium. The medium thickness in the tip and root regions is reduced which helps "set" the flute contour (5). Greater caliper reductions are obtained under hot corrugating conditions than cold conditions as noted in the previous progress report.

The web tension and transverse compressive stresses oscillate in magnitude during the formation of each flute due to the up- and down- motion of the top corrugating roll (16,18) and possible draw variations in the labyrinth. The stress oscillations occur in hot forming and are believed to also occur in cold forming. Figure A5 illustrates the oscillatory nature of the web tension, top corrugating roll pressure and "up-and-down" corrugating roll acceleration under hot conditions (18). The fundamental frequency of the oscillating forces is the flute forming frequency but large higher harmonics are usually present. The variations in web tension are particularly important because they will be magnified in the labyrinth. Substantial cyclic peaks in web tension could occur as a result.

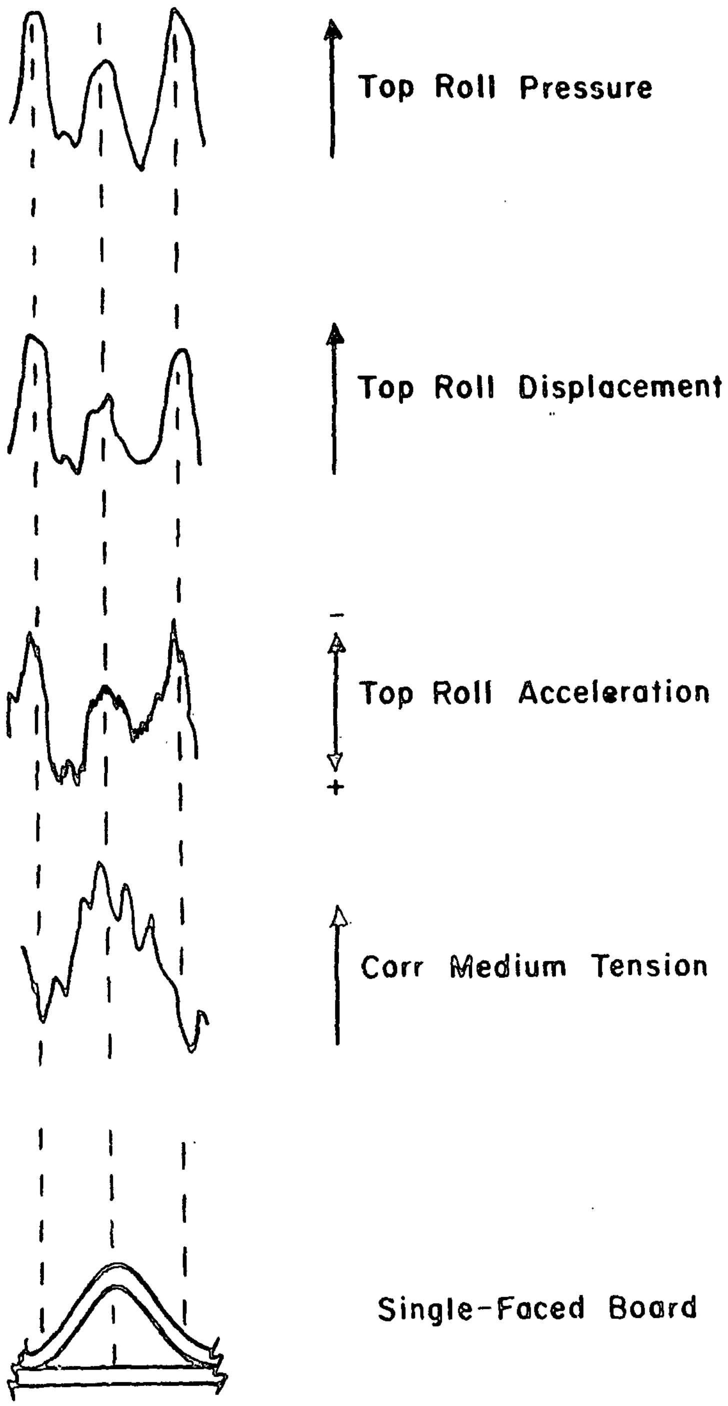


Figure A5. Oscillatory Nature of Corrugating Forces and Corrugating Roll Displacement (Ref. 18)

Temperature and Moisture Effects in Corrugating

Various authors have emphasized the importance of corrugating temperature on both flute fracturing and high lows (See Ref. 6-8, 19-21). It is believed that the lignin and hemicellulose components in the medium become more plastic and "flow" at high corrugating temperature, particularly if somewhat moist. The "flow" of these components is believed to assist the medium in forming to the flute contour and in retaining its flute shape so as to minimize high-low flute formation in the hot process. This hypothesis explains many of the phenomena observed in normal corrugating with hot (350°F) corrugating rolls. However, we have shown that corrugating can be carried out under room temperature conditions where thermal softening effects do not occur. It also may be remarked that the new fingerless corrugators have reduced high-low problems (22-24) under hot conditions and presumably will do so under cold conditions.

Cold vs Hot Corrugating Flat Crush

Most commercial mediums can be corrugated satisfactorily under cold conditions. In general, the properties of the cold formed board are about the same or better than obtained under hot corrugating conditions. However, cold formed board made with some mediums exhibits lower ultimate flat crush strength than hot formed board. While the ultimate flat crush strengths may differ, the initial portions of the load-deflection curves are comparable for cold and hot formed board (Fig. A6). The first peak strengths are approximately equal for all commercial mediums evaluated to date. Thus, cold and hot formed board should show about the same response when subjected to low degrees of crushing by pull rolls and belts.

When combined board is crushed between rigid steel rolls, all boards (hot or cold formed) will suffer the same amount of caliper reduction. Medium

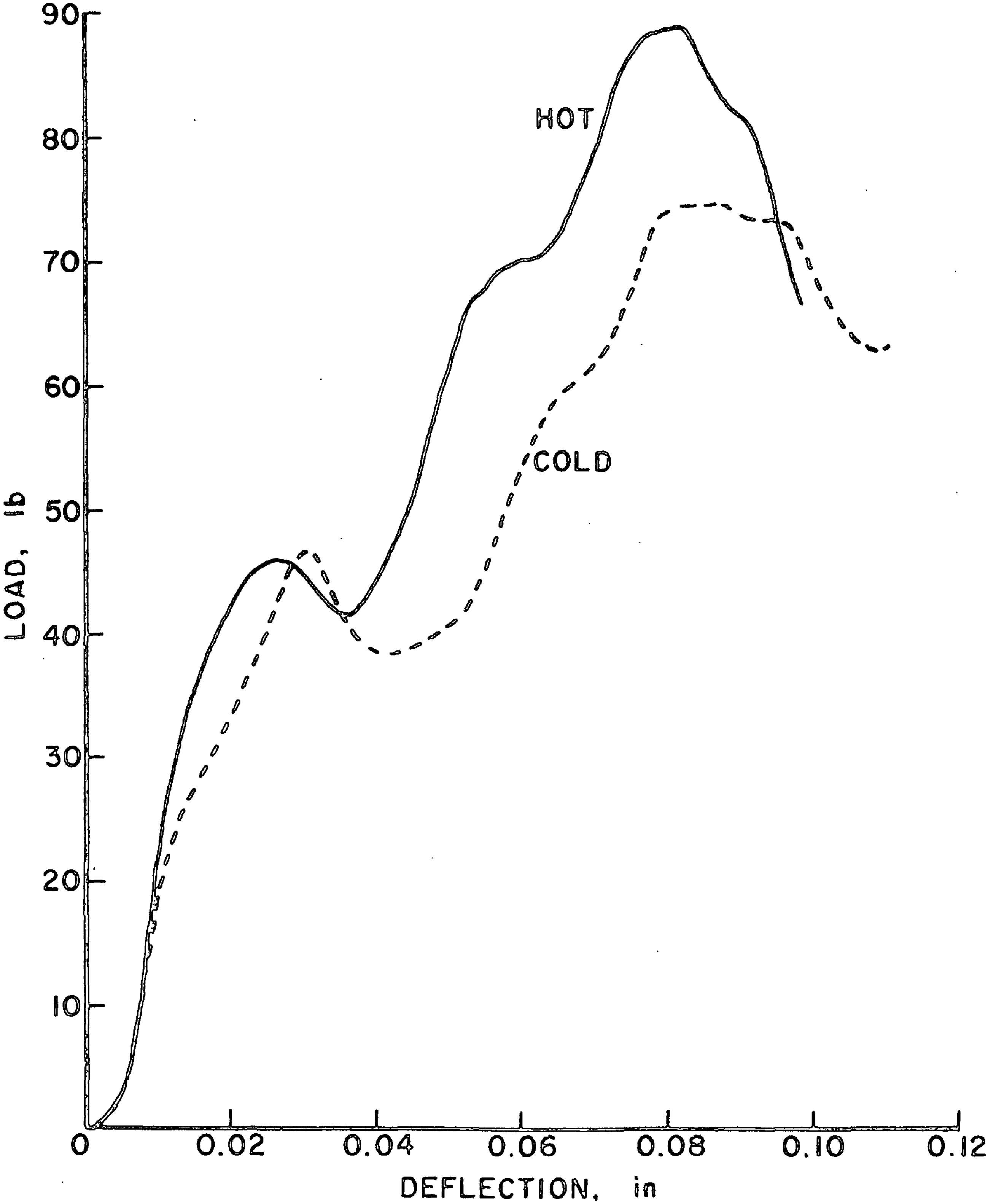


Figure A6. Typical Flat Crush Load-Deflection Curves for Cold and Hot Formed C-Flute Board stiffness and weight will have no effect on the degree of caliper reduction and degradation in other properties dependent on the effective caliper. Most of the literature discusses roller crushing effects.

On the other hand, if boards (hot or cold formed) are subjected to the same transverse stress, boards with stiffer mediums will crush less than boards with weaker mediums. Thus, for a given load, the board with stiffer, heavier medium should exhibit less degradation in board properties. This stressing process is more likely to occur in transportation, e.g., humping operations.

Early work at the Institute was concerned with the effect of crushing on combined board properties and the flat crush fatigue behavior of combined board (hot corrugated) (25,26). The shape of the flat crush load-deformation curve was discussed (26), and it was pointed out that loads greater than the first peak caused significant nonrecoverable deformation, i.e., degradation of the combined board. It was also shown that combined board can withstand many repeated transverse loadings if the applied loads are kept below the first peak load.

In more recent work, Staigle (27), Crisp, et al. (28), and Nordman, et al. (29) discussed the crushing of hot formed combined board in the converting process by feed rolls and belts. Staigle (27) showed that the permanent loss in caliper as measured using the TAPPI procedure is much less than the actual caliper reduction when board is passed between steel rolls. Thus, a permanent caliper loss of 10 mils may result from a roll crush treatment of 40 mils. In Figure A6, a 40 mil reduction in caliper would cause nonreversible deformations and degradation of board properties would be expected even though the permanent caliper loss is much less than 40 mils. Crisp (28) also crushed board between rollers and evaluated the changes in board properties. He defined "hardness" as the greatest flat crush load up to 0.010

inch deflection and concluded hardness was more sensitive to board damage than caliper. Thus, the early portion of the flat crush curve was considered to be more important insofar as box plant crushing is concerned, although hardness decreased much more than box compression. The flat crush test was not suitable as a damage indicator because the maximum flat crush load was not affected by small amounts of crushing.

Nordman, et al. (29) studied crushing of hot formed combined board between steel rolls and confirmed Staigle's work on caliper recovery. The major portion of the reduction in thickness due to roller crushing is recovered. However, the effective structural thickness has actually decreased because the fluted medium is damaged. Thus board properties dependent on the effective thickness are reduced. Both Crisp and Nordman found that flexural stiffness, caliper, first peak flat crush load, and box compression decrease with increasing degrees of crush, particularly as the flat crush first peak deformation is exceeded. However, the decreases in box compression strength do not necessarily accelerate until extreme degrees of crush are imposed. Cold formed board should exhibit the same trends as obtained in the above studies on hot formed board. This will be verified on cold formed corrugated board boxes made under this program at the Union Camp Corporation.

Morris (30) has emphasized that satisfactory container performance during transportation is important. In transportation, the loaded box must cope with repeated applications of stress at low to high levels. He contends that medium stiffness is an important factor in maintaining box compression performance potentials through the transportation environment. He believes the field box continues to function until we crush the legs of the flute, i.e., flat crush test failure. This contention is probably consistent with the box results after crushing which were obtained by Crisp and Nordman (28,29). As a final comment, the results in

Ref. 29 show that precrushing board to given stress levels causes reductions in box compression which vary with medium stiffness as well as flute and other factors. Briefly summarizing, it appears that:

(1) The initial portion of the flat crush load-deflection curve is more critical than ultimate flat crush in assessing whether a given degree of crushing will degrade board quality. In this regard, cold formed flutes should perform as well as hot formed flutes.

(2) The entire load-deflection curve is important to box performance because boxes can continue to function even though the crushing has exceeded the first peak deflection. For this aspect of end-use performance, cold formed board may show a slight disadvantage. One of the aims of this research is to improve corrugating medium with respect to flat crush performance. Results from this work should be applicable to both processes.

Discussion of Results

For our initial work, we focused attention on the machine direction (m.d.) and cross direction (c.d.) edgewise compressive characteristics of the medium as related to forming conditions. The compressive characteristics of the medium affect the converting performance of combined board and end-use box performance. The medium contributes directly to c.d. short column strength (along with the liners) and indirectly to flexural stiffness where it serves primarily to maintain the desired liner separation. The latter involves the flat crush load-deformation characteristics of the formed medium and, hence, the m.d. edgewise compressive properties of the medium. Crushed combined board, whether in converting or end-use, is a weak product. Thus the compressive characteristics of the medium in both directions are involved in box performance.

Accordingly we planned and carried out work in the following areas:

1. Evaluation of the effect of cold forming conditions on the

compressive characteristics of the medium and comparison with hot formed medium. Other properties such as tensile and bonding strength were also considered.

2. Effect of forming conditions on flute shape.

3. Relation of flat crush to medium properties - structural models.

Forming Conditions vs Medium Properties

Most of our work was carried out using four commercial 26 lb. mediums. There were three semichemical mediums and one recycled fiber medium. As expected, the recycled fiber medium contained a higher percentage of long softwood fiber than the semichemical mediums. Two of the mediums exhibited about equal flat crush under cold and hot corrugating conditions; the other two mediums exhibited lower cold than hot flat crush. The physical characteristics of the mediums are summarized in Appendix I together with the general procedures employed.

To determine the degree of change in the edgewise compressive characteristics of formed medium, we made short span compressive tests on fluted but unbonded sections of cold and hot formed medium. The compressive tests were made on the STFI strip compressive tester which employs a test span of 0.7 mm (32). The short test span permits localized strength determinations which are of great value in studying formed flutes.

The machine direction STFI compressive results taken at various positions around the flute are shown in Figures A7 and A8 for the "different" and "equal" cold/hot flat crush mediums, respectively. The results show that the formed medium exhibits much lower compressive strengths than the uncorrugated medium. This is true for both hot and cold formed medium although there are some significant differences which are noted below. Overall the reductions in m.d. compressive strength

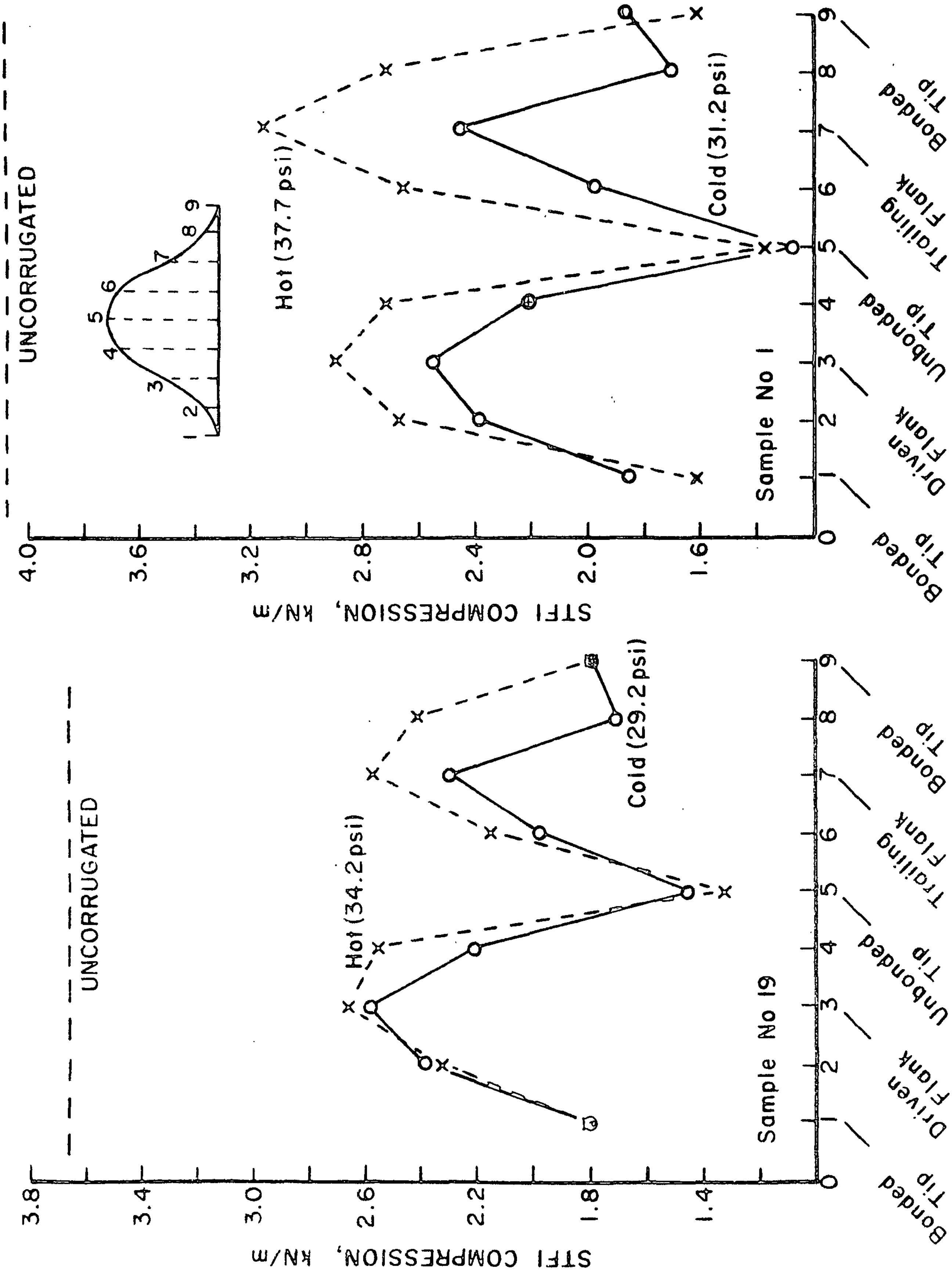


Figure A7. Machine Direction Compressive Strength after Fluting for Mediums Exhibiting "Different" Cold/Hot Flat Crush Strength (Flat Crush Values in Parenthesis)

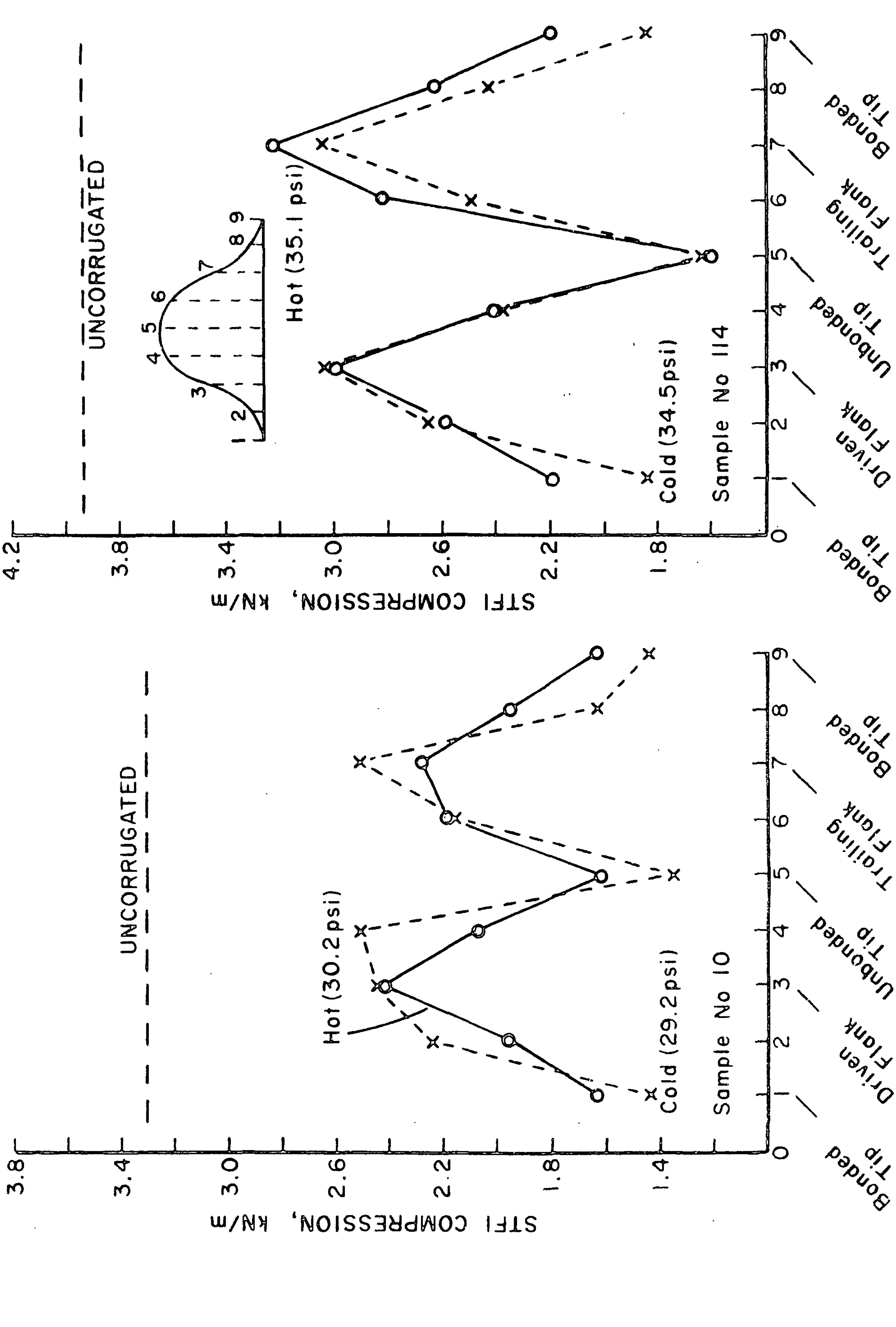


Figure A8. Machine Direction Compressive Strength after Fluting for Mediums Exhibiting "Equal" Cold/Hot Flat Crush Ratios (Flat Crush Values in Parenthesis) were about 42%. We believe the reductions in compressive strength reflect fiber bonding damage caused by the high stresses in the forming process.

The m.d. compressive strengths in the flank and tip/flank regions (positions 2-4 and 6-8) tended to be somewhat lower on the cold formed medium than the hot formed medium in Figure A7. This was more evident on the trailing flank. As mentioned, the two mediums in Figure A7 exhibited lower cold than flat crush. In the case of the mediums where the cold and hot flat crush results were comparable, the compressive strengths of the hot and cold formed mediums were also about the same (Fig. A8).

Figure A9 shows that the STFI compressive strengths in the tip-flank region are well related to flat crush for both the hot and cold formed boards. In contrast, the STFI compressive results on the uncorrugated medium were not well related to the flat crush results on the cold-formed medium. This helps confirm that degradation of the m.d. edgewise compressive potentials of the medium due to forming is a factor in flat crush performance.

When single-faced board is tested in flat crush the medium at the unbonded tip flattens and squares off as the first load peak is reached (See Fig. A10). Note that the cold formed board deformed less symmetrically and exhibits a broader flattened off portion. This would be expected if the compressive characteristics of the trailing flank were weakened more than the leading flank as occurred in Figure A7. The flank/tip regions may be particularly critical because the "hinge" points are formed in these regions during the flat crush test.

At failure in flat crush the medium forms a hat shaped (frame) structure (See Fig. A11). The figure also illustrates that the cold-formed medium failed in a less symmetrical manner than the hot medium. In this example final failure appeared to be associated with the trailing flank for both forming conditions.

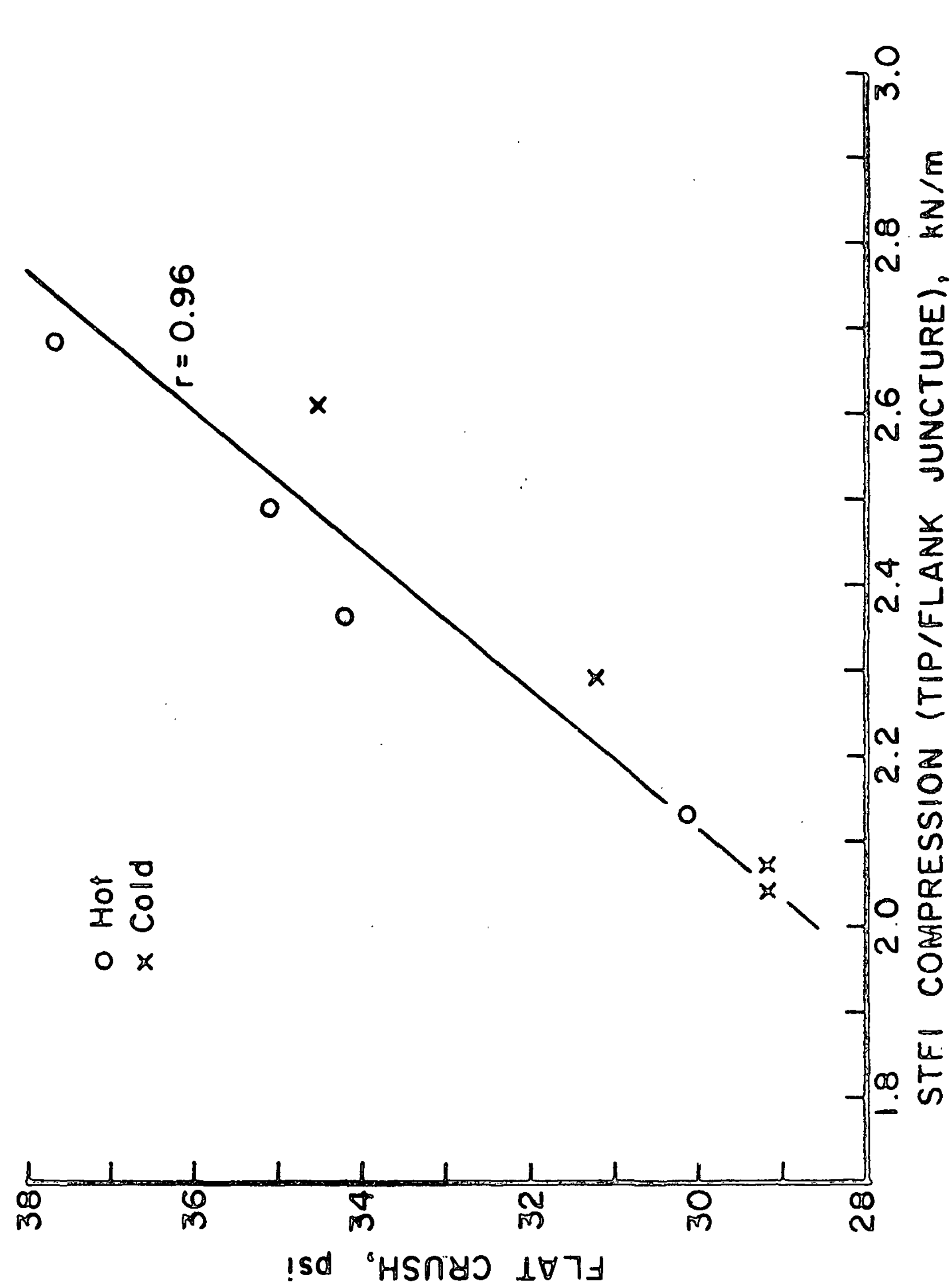


Figure A9. Relation Between Compressive Strength of the Fluted Medium and Flat Crush

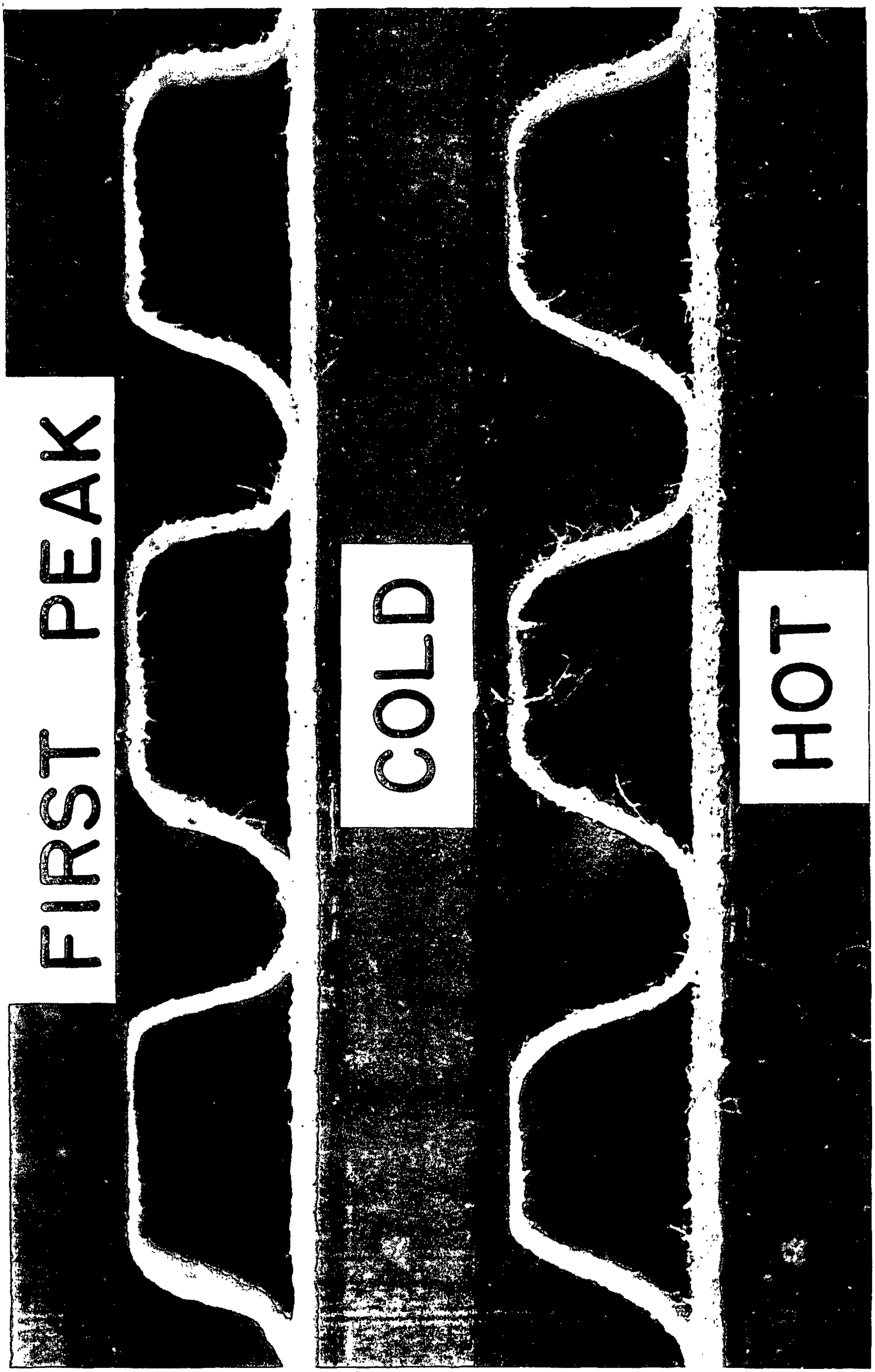


Figure A10. Appearance of Cold and Hot Formed Board at the First Flat Crush Peak (Trailing Flank to Right)

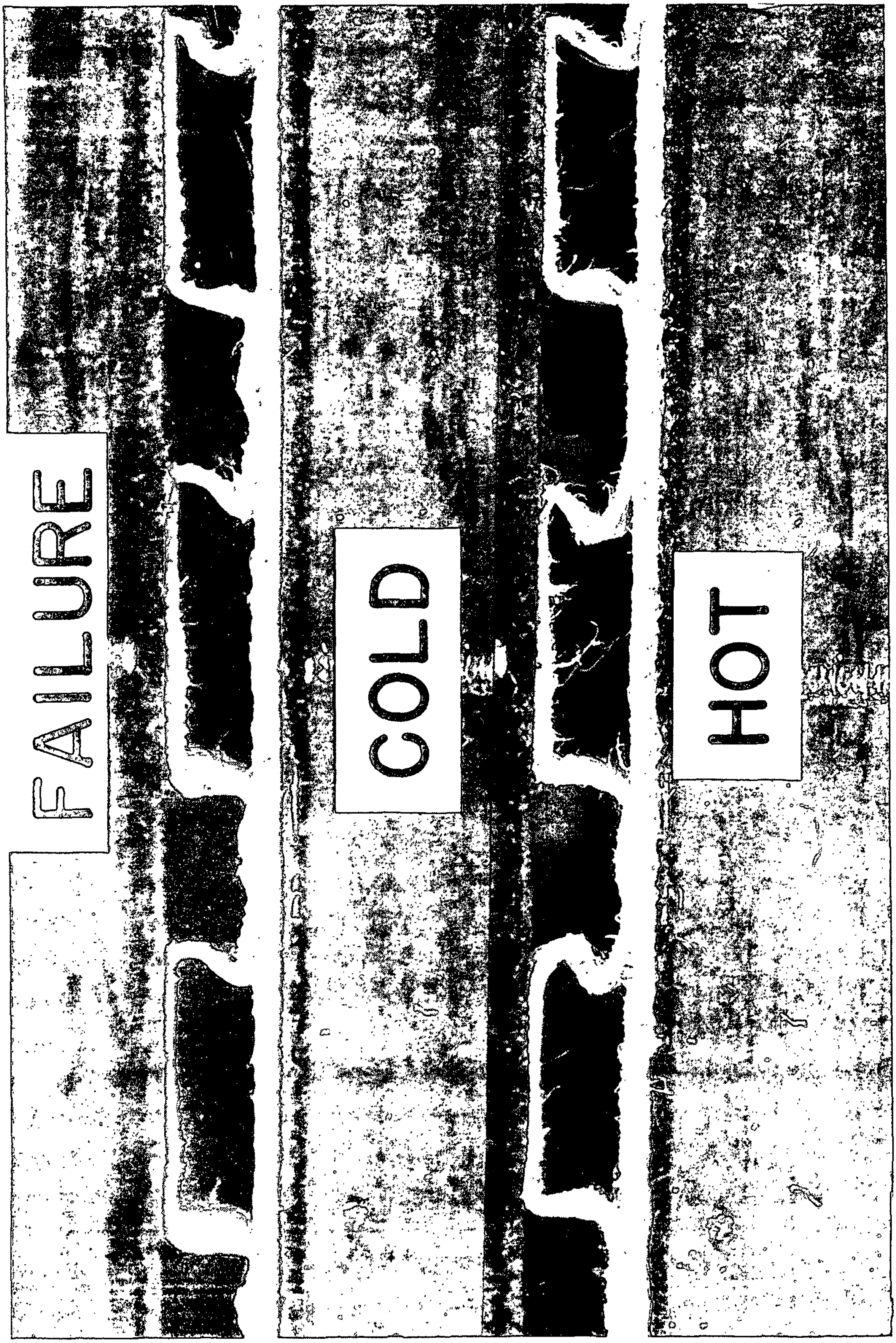


Figure A11. Appearance of Cold and Hot Formed Board at Flat Crush Failure (Trailing Flank to Right)

Based on observation and experiment, we believe it is reasonable to expect that the flat crush load-deformation characteristics should be related to the m.d. edgewise compressive properties of the formed medium. Thus the lower ultimate flat crush strength obtained with some mediums under cold conditions is a result of the greater compressive strength degradation in the flank/tip and flank regions of the flute.

Short span m.d. tensile tests on the formed medium showed reductions in strength ranging from about 17-44% compared to the uncorrugated medium on sample 1 (Table I and Fig. A12). In all cases the percentage reductions in tensile strength were less than in edgewise compressive strength, often much less. Thus, while forming affected both the tensile and compressive characteristics of the medium, compressive strength was more drastically lowered. We speculate this occurs because compressive strength is more sensitive to the delamination stresses which are induced in the forming process.

Figure A12 shows that the cold formed medium generally exhibits lower tensile strength than hot formed medium in all flute positions. However the tensile strengths varied more erratically with flute position than compressive strength. In any case the reductions in tensile strength did not appear to be directly related to the cold-hot flat crush differences although they may affect other board qualities. This is not surprising because the flat crush load-deformation characteristics would be expected to be primarily dependent on the compressive characteristics of the medium.

We also carried out STFI edgewise compressive tests in the cross-machine direction on hot and cold formed medium. No separation by position on the flute was possible. Figure A13 indicates that forming reduces the edgewise compressive strength

TABLE I

EFFECT OF FORMING ON THE LOCAL TENSILE AND COMPRESSIVE STRENGTH OF THE MEDIUM

(Medium Sample 1)

Flute Position	Forming Condition	Compressive Strength,[b] kN/m	Diff., %[a]	Short Span Tensile,[b] kN/m	Diff., %[a]
Uncorrugated	--	4.08	--	10.7	--
Corrugated					
Bonded root	Cold	1.86	-54.4	7.32	-31.6
	Hot	1.61	-60.5	7.65	-28.5
Root/driven flank	Cold	2.40	-41.2	6.58	-38.5
	Hot	2.67	-34.6	8.89	-16.9
Driven flank	Cold	2.55	-37.5	8.25	-22.9
	Hot	2.89	-29.2	7.62	-28.8
Unbonded tip/ driven flank	Cold	2.32	-43.1	6.63	-38.0
	Hot	2.71	-33.6	7.37	-31.1
Unbonded tip	Cold	1.28	-68.6	6.01	-43.8
	Hot	1.37	-66.4	8.65	-19.2
Unbonded tip/ trailing flank	Cold	2.11	-48.3	6.04	-43.6
	Hot	2.65	-35.0	8.35	-22.0
Trailing flank	Cold	2.45	-40.0	8.09	-24.4
	Hot	3.14	-23.0	8.05	-24.8
Bonded root/ trailing flank	Cold	1.86	-54.4	7.93	-25.9
	Hot	2.70	-33.8	8.30	-22.4

[a]Based on uncorrugated results as reference.
[b]STFI compressive and short span tensile spans were 0.7 and 1.27 mm, respectively.

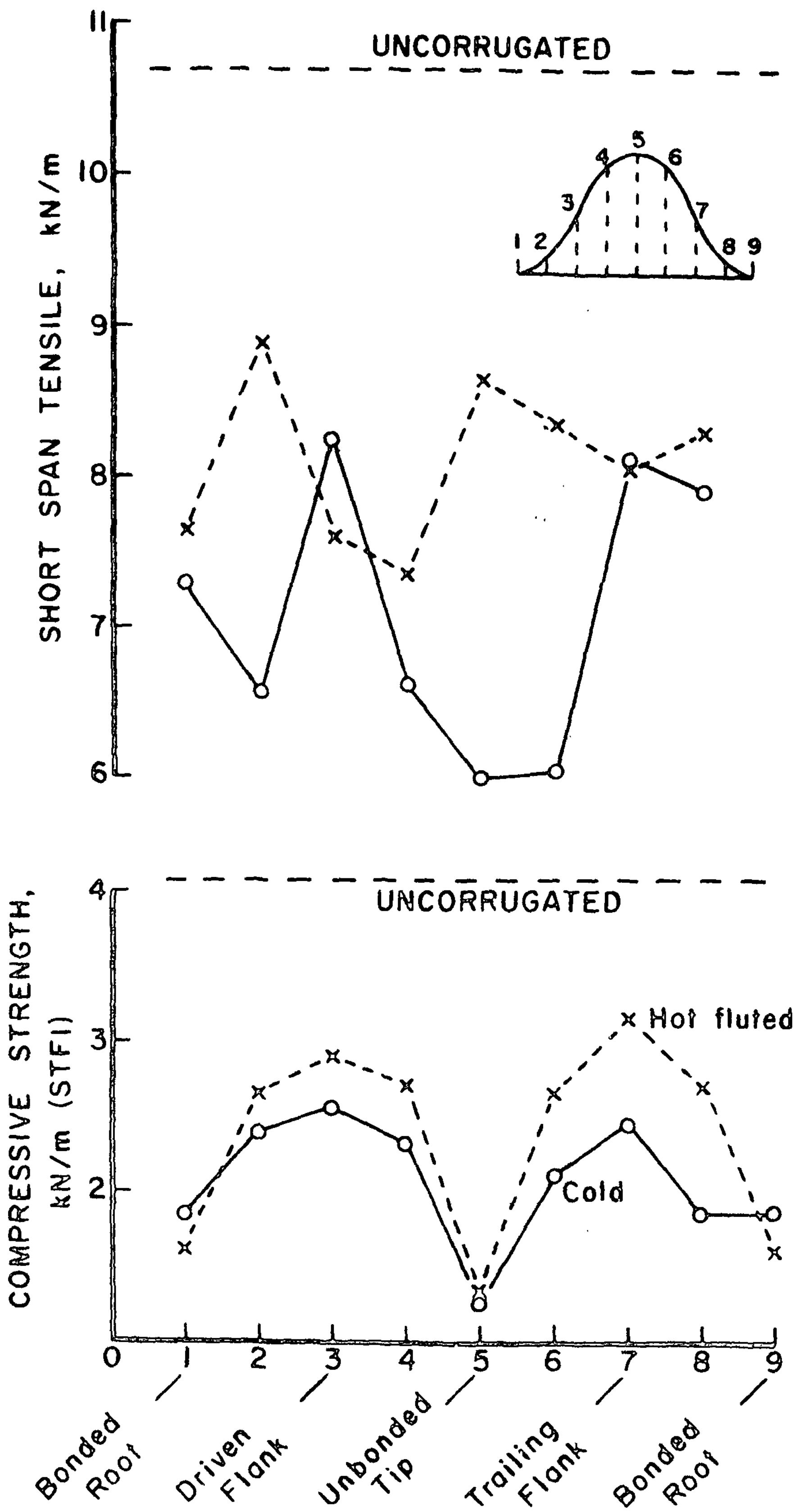


Figure A12. Effect of Forming on Short Span Tensile and Edgewise Compressive Strength of Sample 1

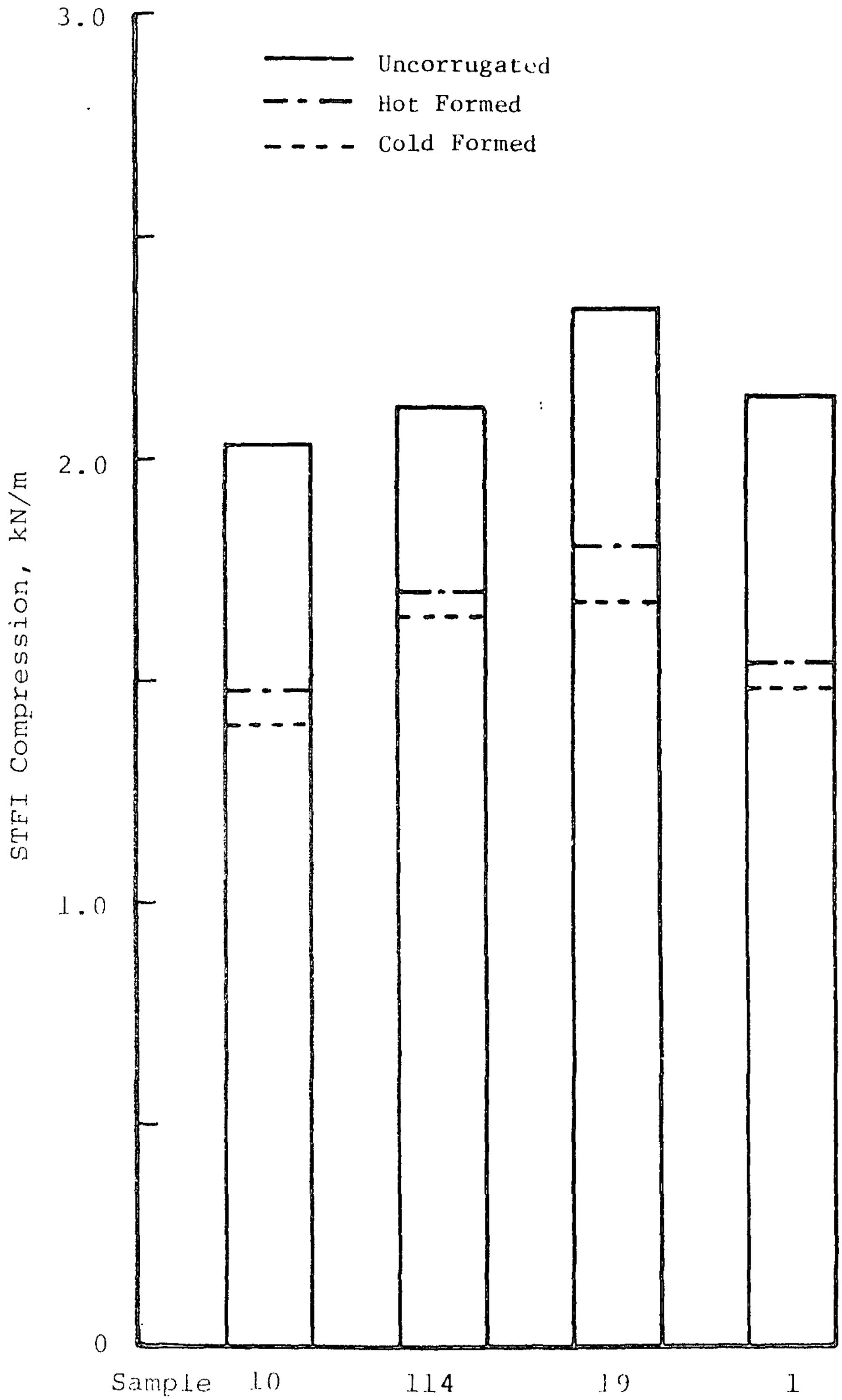


Figure A13. Effect of Forming on Cross-Direction Edgewise Compressive Strength potentials of the medium in the cross direction. This is probably due to delamination induced by shear stresses in forming as mentioned previously. The reductions are in the neighborhood of 20 to 30% and are not greatly different for hot and cold corrugating. Top load box compressive strength is dependent, in part, on the cross direction strength of the medium. Thus, these findings are significant because they indicate that the corrugating process degrades the compressive potentials of the medium in the c.d. as well as in the m.d.

In addition to determining how forming affects compressive strength, tests are in progress involving bonding strength and the transverse shear characteristics of the medium. In Figure A14 the Viscosity-Velocity Product (VVP) type bonding strengths in the machine direction of the hot and cold formed mediums are significantly lower than for the uncorrugated medium. Cold forming tends to give slightly greater reductions. It appears likely that the reductions in edgewise compressive strength are due to these losses in bonding strength. This seems particularly true in view of the delamination which accompanies compressive failure. Losses in shear strength may also be involved and work is in progress to develop a transverse shear test. We should note that the bonding strength tests on the formed medium involve nonideal test conditions; therefore the results are probably only an approximation to the state of the medium after forming.

Thickness direction tensile (ZDT) bonding strength tests were also carried out as shown in Figure A15. Generally the formed mediums exhibited lower ZDT strengths than the uncorrugated medium. However, the decreases in ZDT strength varied considerably from medium to medium and the decreases were probably not significant in some cases. These results appeared to be less revealing than the VVP type tests.

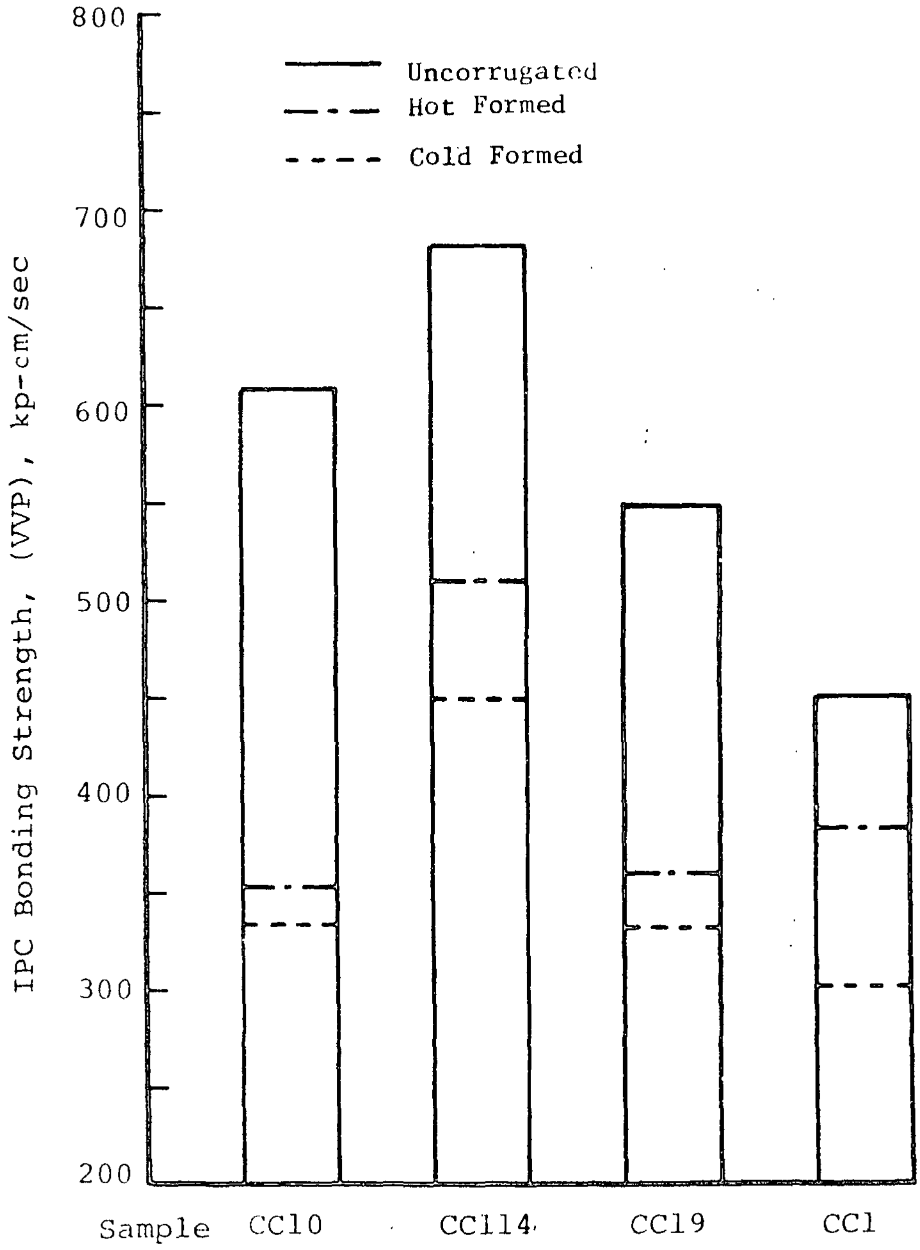


Figure A14. Effect of Forming on Transverse Bonding Strength in the Machine Direction

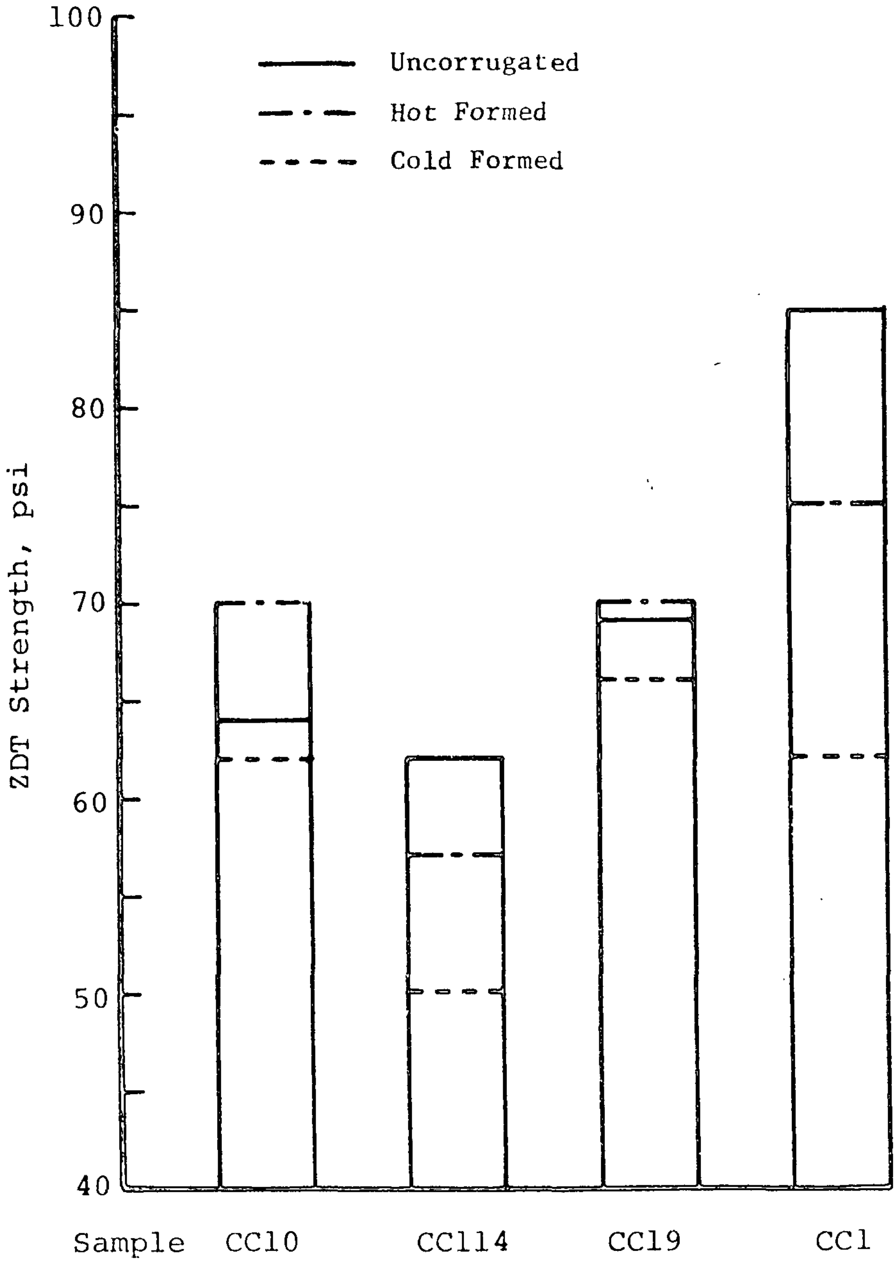


Figure A15. Effect of Forming Conditions on ZDT Strength

Briefly summarizing it appears that:

1. The edgewise compressive and tensile strengths of medium are greatly reduced by fluting under both hot and cold conditions. We speculate that this is due to fiber-fiber bond damage during fluting.
2. Some mediums show more evidence of compressive strength reduction under cold conditions than under hot conditions. We believe this accounts for the lower flat crush obtained with such cold formed mediums.
3. We also noted that some mediums tend to exhibit more compressive degradation on the trailing flank than on the driven flank under cold fluting as compared to hot fluting conditions.

Effect of Type of Forming Stress

Work is in progress to determine how various types of stress such as exist in corrugating bring about compressive strength reductions. Our initial experiments involved prestressing medium in tension and combined bending and tension at standard test conditions, 73°F and 50% R.H. The properties of the medium under these test conditions will approximately correspond to those in cold corrugating.

As a first step we loaded m.d. specimens of medium in tension to failure. The remnants were then evaluated for compressive strength using the STFI tester. Figure A16 shows that prestressing in tension has little or no effect on compressive strength.

In cold or hot corrugating the onset of fracturing is usually gradual over a range of speeds. Also fractures do not usually propagate across the web "instantaneously" as occurs in long-span tensile tests. Within the labyrinth, it may be speculated that the medium is locally stretched far enough to produce fiber

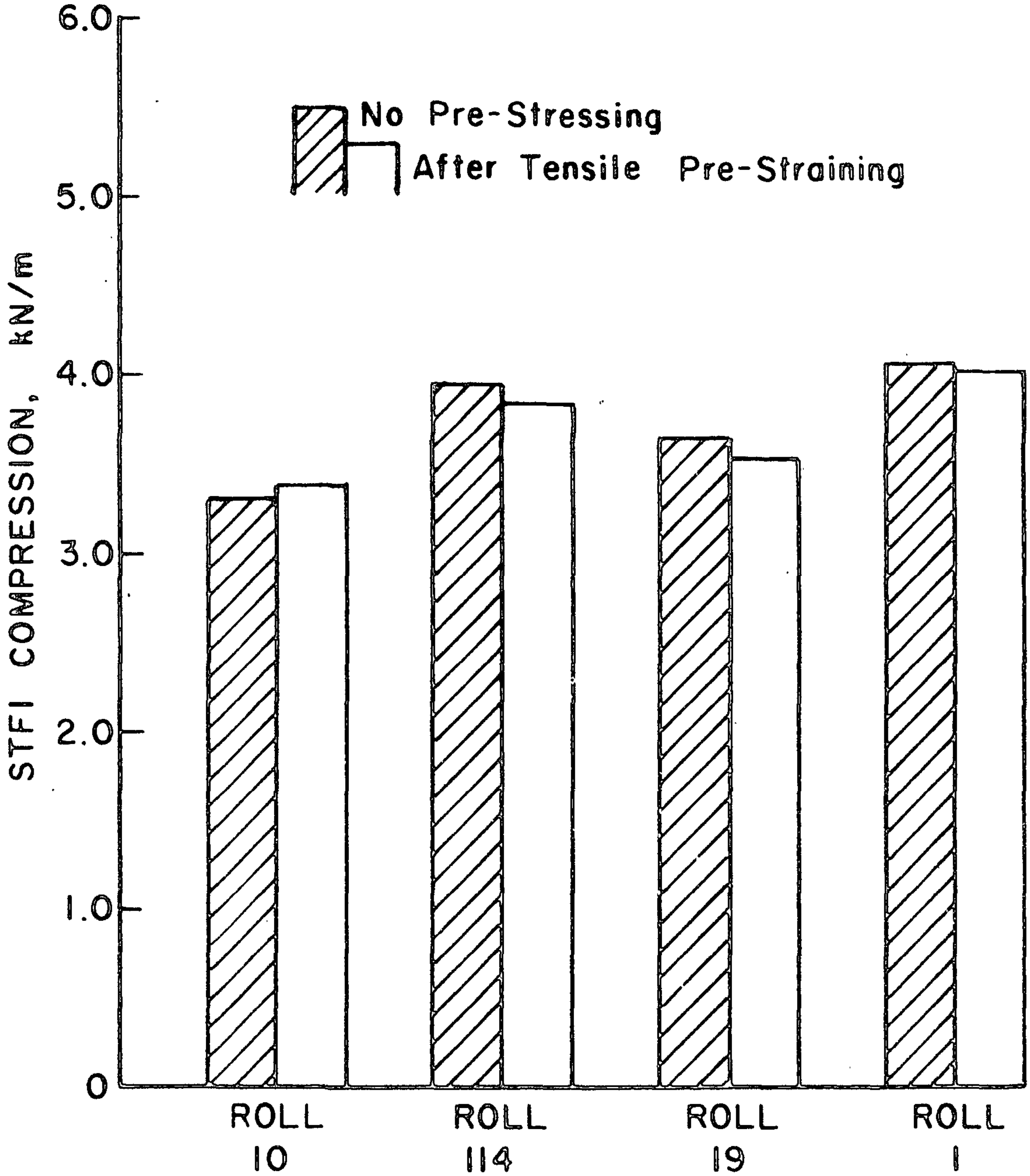


Figure A16. Effect of Tensile Prestressing on m.d. Edgewise Compressive Strength bond damage and to affect compressive strength but there is insufficient stored energy to cause tensile fractures to propagate. This behavior would be somewhat analogous to a short span tensile test on a "stiff" tester. In such tests there is often no visible indication of failure at the maximum load and no "instantaneous" failure is encountered. However, compressive strength might be lowered under such conditions.

When medium is preflexed by bending it around a small radius under low tension, the m.d. compressive strength after flexing is greatly reduced (Fig. A17). The smaller the radius, the greater the loss in compressive strength. Our results show that the bending stresses during forming could be partly responsible for the losses in m.d. compressive strength of the fluted medium. Because the tip and root radii of the corrugating rolls are relatively small, both bending and shear stresses are involved in forming medium to the flute contour as mentioned earlier.

The combined effects of bending and tension are illustrated in Figure A18. Figure A18 shows that the compressive strength decreases rapidly as the wrap angle used in flexing increases from 0 to about 90°. Contact angles between the medium and the flute tip are about 90-120° near the center of the corrugating labyrinth (9,10). The results in Figure A18 also indicate that the losses in compressive strength are aggravated by higher tensions and smaller radii. Past work has indicated that high web tensions occur in the corrugating labyrinth as friction between the medium and steel rolls increases. We believe that Figure A18 indicates that higher web tensions will also affect properties of the formed board such as compressive strength, depending on the forming conditions such as temperature, speed, and moisture.

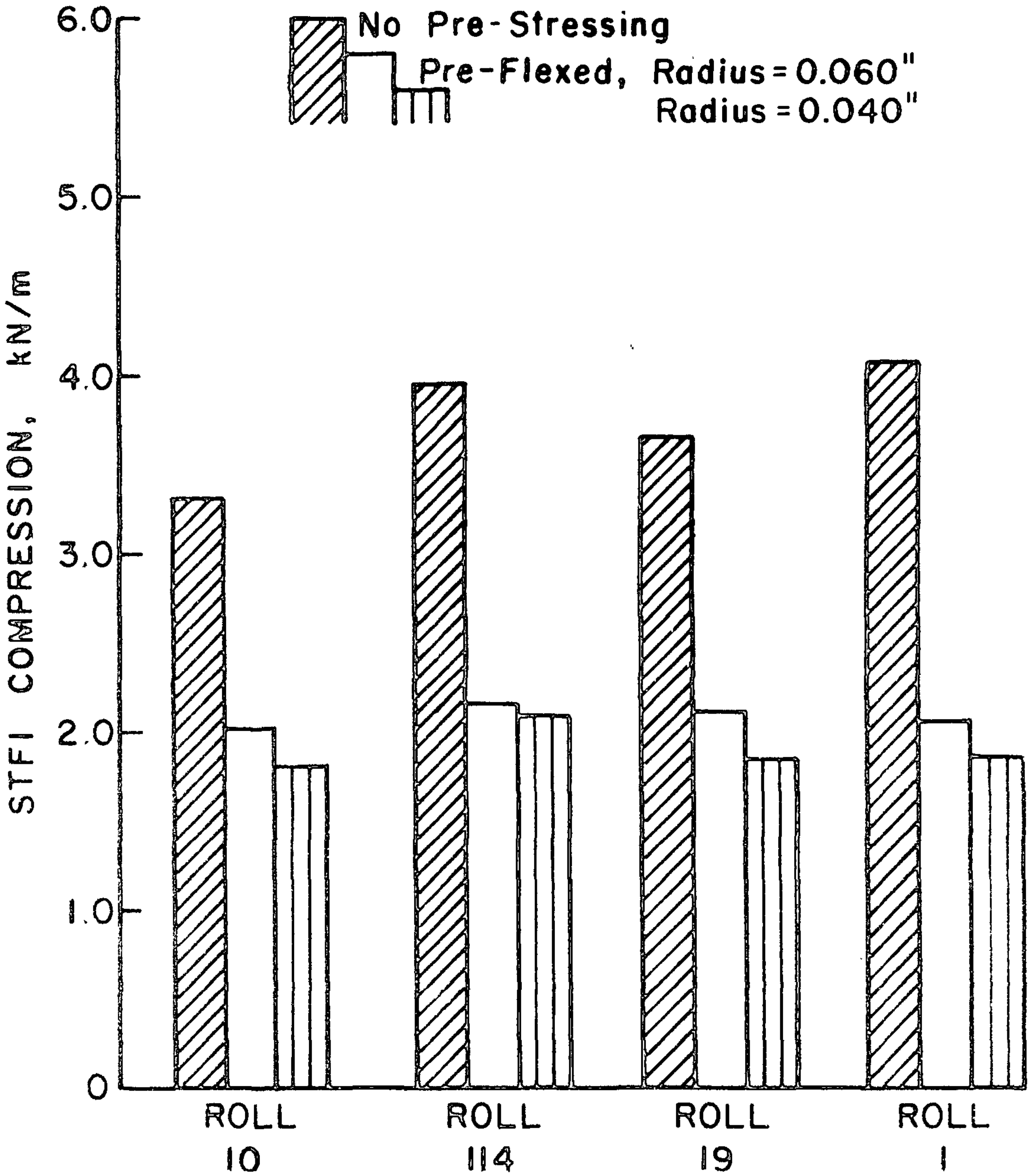


Figure A17. Effect of Bending Prestressing on m.d. Compressive Strength

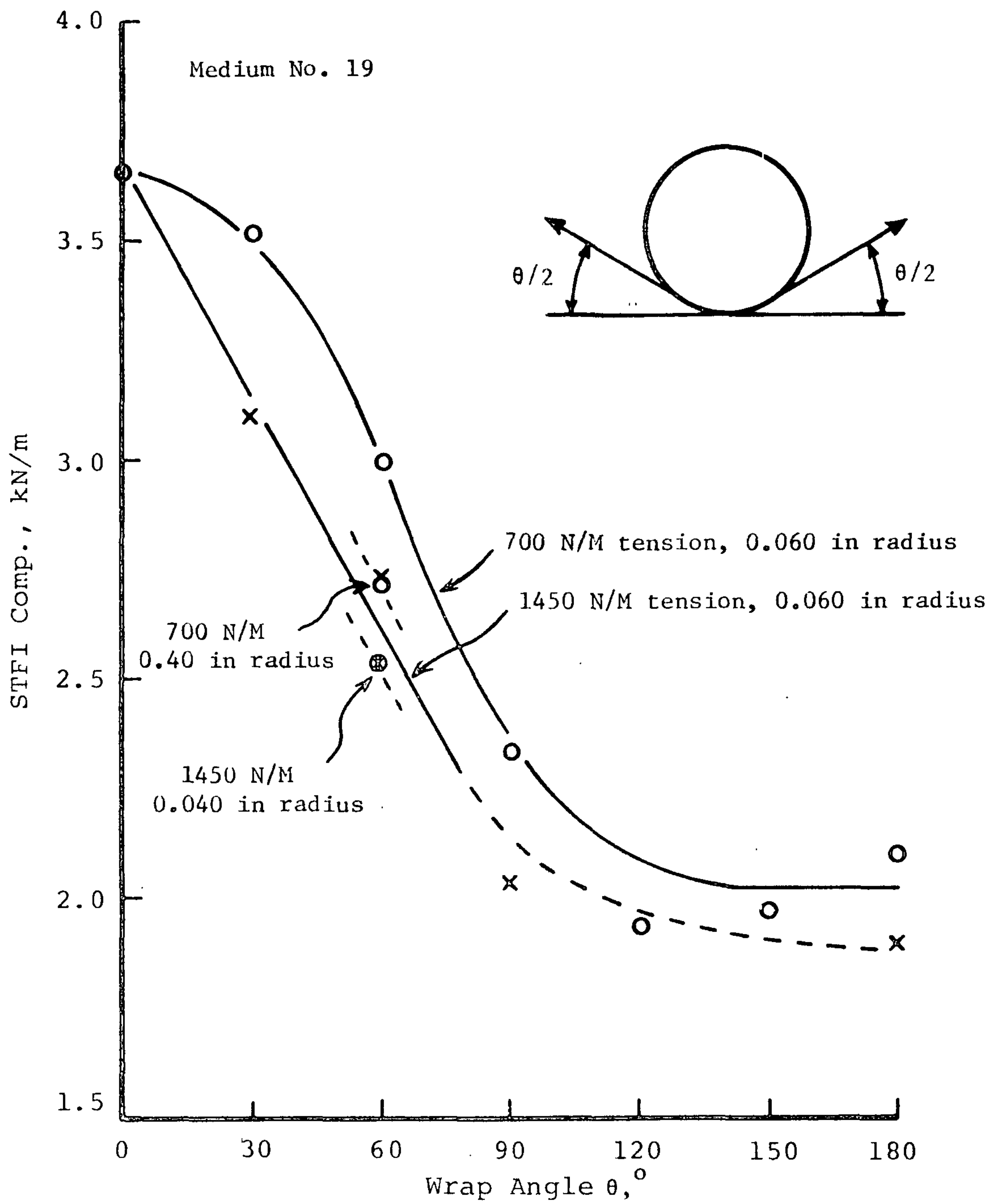


Figure A18. Effects of Tension and Flexing Conditions on m.d. Compressive Strength

The moisture content of the medium at time of forming will affect stiffness and moldability. Under cold forming conditions higher moisture contents should permit the medium to be bent to the flute radius with less damage and enhance its molding to the flute shape. This assumes that friction is held constant or reduced. We have partially confirmed this in past cold corrugating trials over a limited moisture range indicating that higher moisture content promotes higher flat crush.

To determine how flexing at various moisture contents would affect compressive strength, trials were carried out at RH levels ranging from about 15% to 90%. Figure A19 shows that the compressive strengths of the flexed mediums decreased at about the same rate as the unstressed control at high levels of moisture.

Limited trials were also carried out in which the medium was pre-flexed at various moisture contents and then reconditioned to 50% RH prior to compression testing. It was speculated that the flexing at high RH would have less severe effects than at 50% RH and, hence, would not reduce compressive strength as much. However, the effects of the high RH flexing seemed to result in about the same compressive strengths at 50% RH as flexing and testing at 50% RH. We did note, however, that the reductions in compressive strength for the various mediums seemed to be related to the VVP bonding strength.

Forming: Shear and Clearance Factors

In the forming process (cold or hot) large bending and shear stresses are induced in the medium as it is formed to the flute contour. A qualitative analysis shows that formation of the flute cannot occur by pure bending because this would require very large machine direction stretch values (5,9,10).

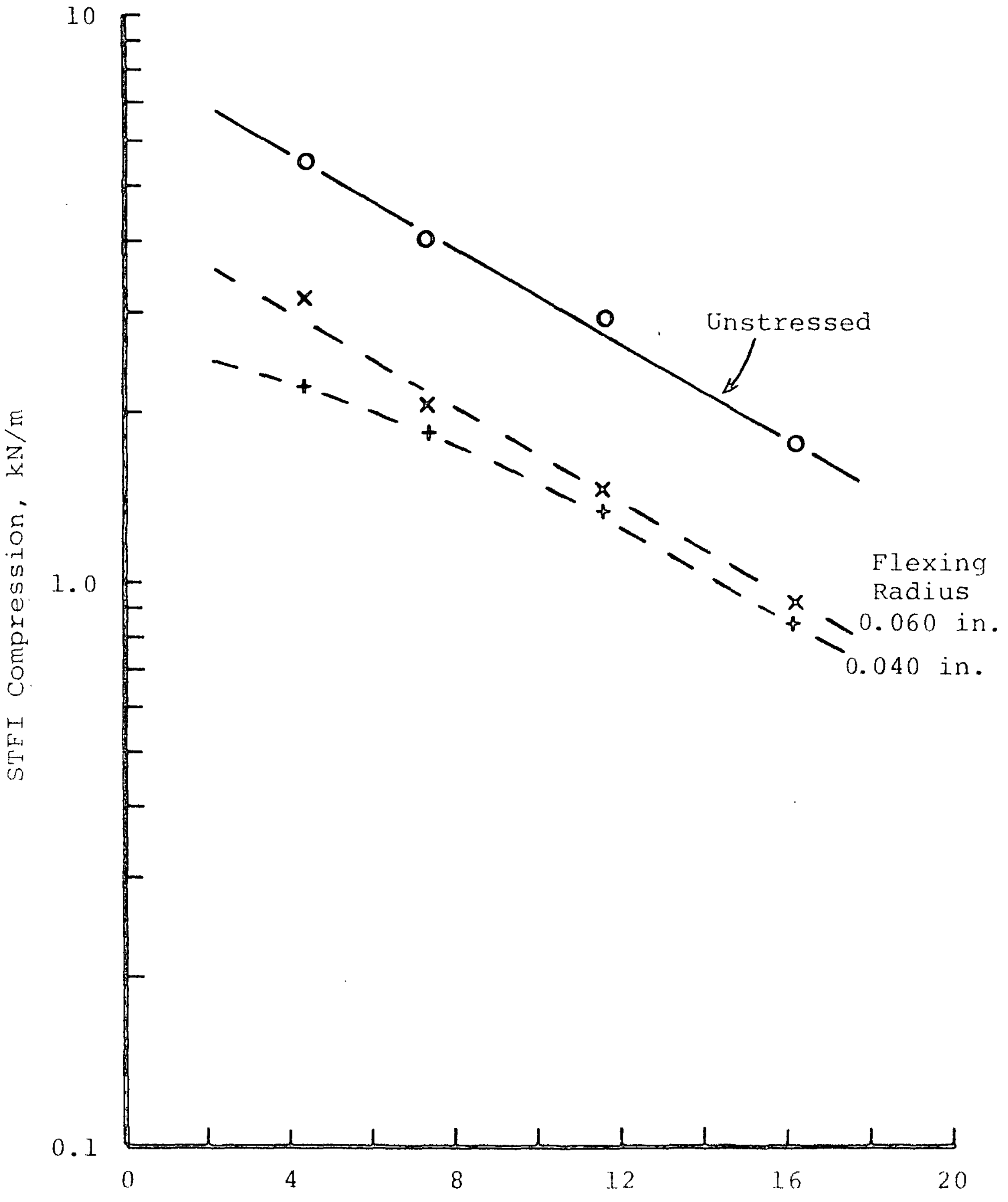


Figure A19. Effects of Flexing at Various Moisture Levels on Compressive Strength

The results of a qualitative analysis are illustrated in Figure A20. If the medium accommodates itself to the flute contour by bending only (no shear strain) the required machine direction strain is at least 8%. Thomas (10) indicates even higher stretch values may be necessary. On the other hand, if only shear stresses were involved, a very high shear angle would be required and the medium would essentially behave like a deck of cards. The apportionment of the strain between bending and shear will depend on the ratio of the bending and shear stiffnesses (elastic and unelastic) of the medium. If the medium is stiffer in bending than in shear, flute formation will involve large shear strain and small bending strain, and vice versa. As an example for given shear and bending properties the strains will increase along some path OY in Figure 20 as the flute is formed. The intersection point Y shows what strain levels the medium must withstand. In this example, the medium would have to have an available stretch in excess of 3.5% and an allowable shear angle in excess of 0.65 radian to form without failure. Thus we believe that shear properties of the medium are important in corrugating as in folding operations.

Preliminary ultrasonic measurements of transverse shear and extensional moduli are shown in Table II. The m.d. tensile modulus E_x is 30-40 times greater than the transverse shear modulus G_{xz} at 73°F and 50% RH. The low shear moduli indicate that a portion of the molding will depend on shear. These test results are applicable to cold forming however we speculate that similar differences between in-plane and shear moduli can occur under hot forming conditions.

TABLE II
ULTRASONIC SHEAR AND IN-PLANE MODULI

	Medium Sample Number			
	10	114	19	1
MD in-plane modulus, (E_x), psi	588,000	804,000	645,000	929,000
Shear modulus G_{xz}, psi	19,300	19,000	18,400	24,200
Ratio: E_x/G_{xz}	30.4	42.2	35.0	38.5

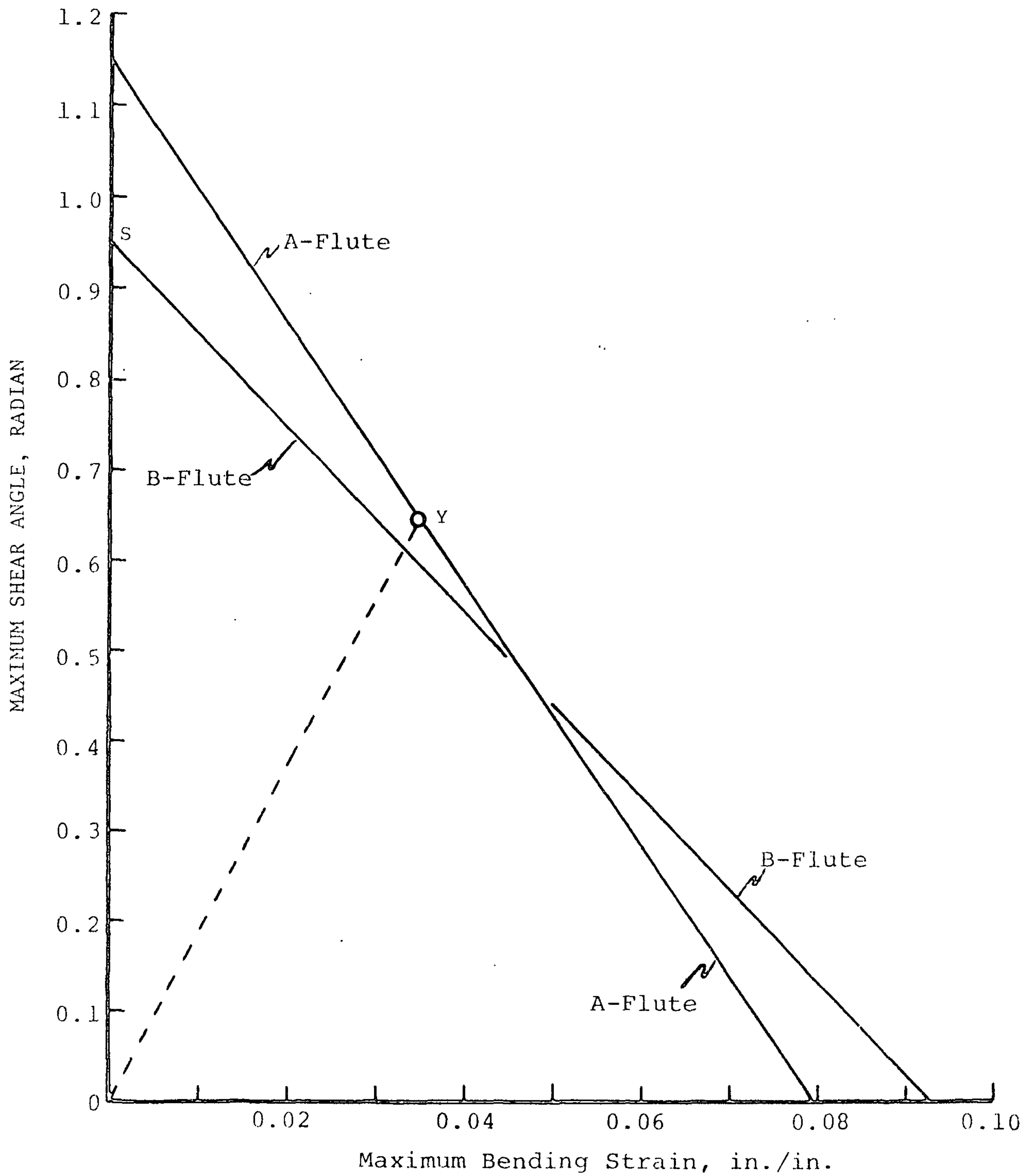


Figure A20. Relationship Between Bending and Shear Strain Required for Flute Forming (Ref. 9)

Transverse shear measurements are difficult to carry out. Only a few techniques are mentioned in the literature. We are attempting to develop a technique for obtaining shear load-deformation curves. These will supplement and extend the ultrasonic measurements which are restricted to "elastic" displacements. Initial results indicate that the mechanical measurements of the transverse shear moduli will be lower than the ultrasonic values as expected due to strain rate effects. However, considerable work is required to improve the technique so as to better characterize material performance in forming and structural performance applications.

An analysis of clearance in the labyrinth shows that a potential pinch point exists about 1/2 flute ahead of the center line (see Fig. A21). In past work at the Institute, high speed motion photography shows that fracturing under hot conditions occurs before the medium reaches the center line, also by about 1/2 flute. This is also believed to occur in cold forming. The lower roll begins to drive the upper roll at a location about 1/2 flute ahead of the center line. If the full amount of medium has not been drawn into the last half flute, relatively high tensile strains would be imposed due to the pinching action. This would result in the risk of greater medium damage and the occurrence of fracture.

Flute Geometry vs Forming Conditions

In general, the differences in flat crush between cold and hot formed board would be expected to depend on medium characteristics and/or flute geometry. Our current research has been directed to determining whether geometry or material differences due to forming conditions are more important in affecting board quality. The preceding work showed that some cold formed mediums exhibited lower compressive strength after fluting than hot formed board. In these cases the cold board also gave lower flat crush than hot board. In order to determine if flute profile

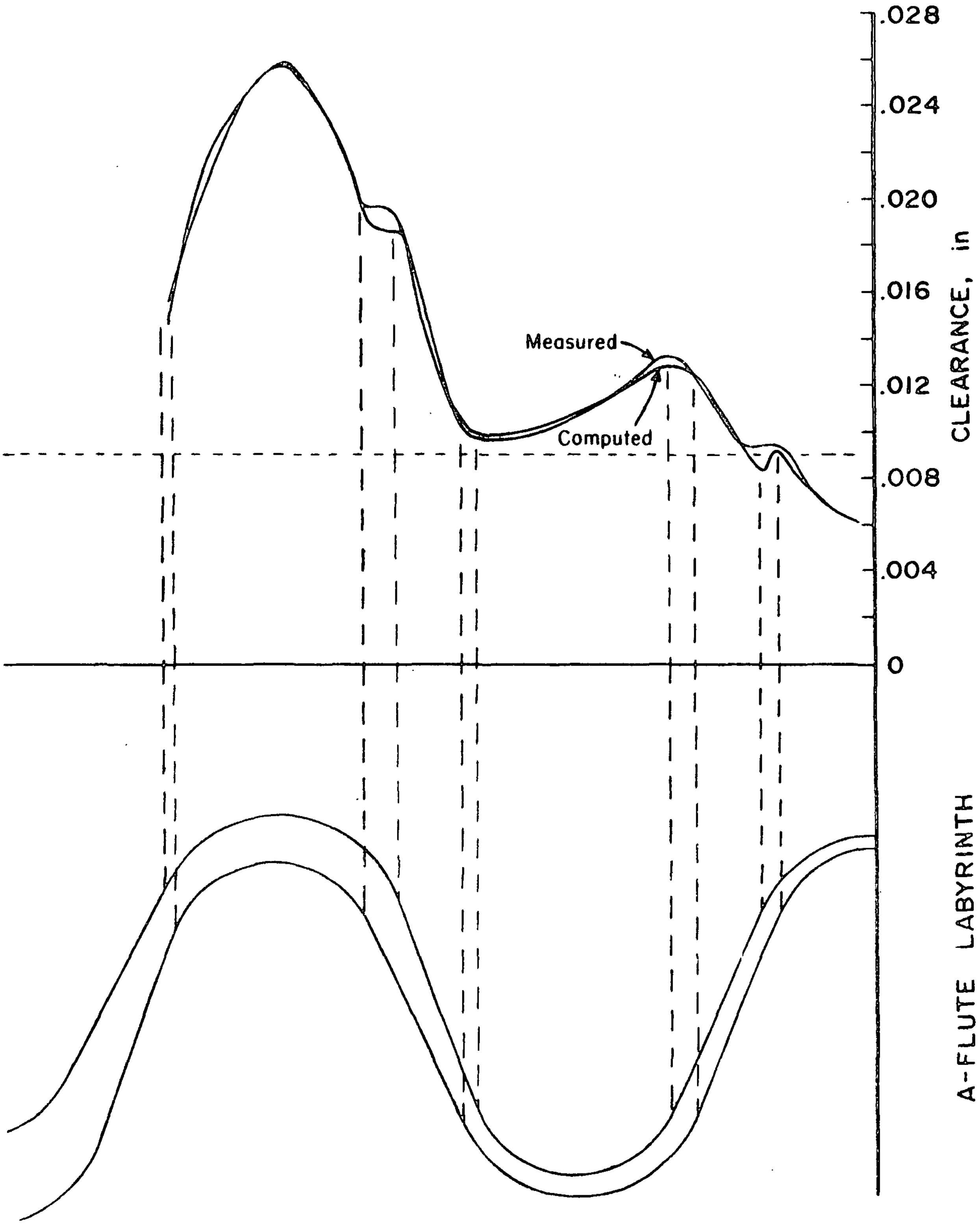


Figure A21. Clearance in Labyrinth

(geometry) differences are also obtained under hot and cold corrugating conditions, a detailed analysis of flute profiles has been carried out.

For this purpose an Autech model AKR Laser Dimension gage was employed to measure the flute profiles (33). The profiles were measured by passing a web of single-faced board under the laser at a controlled speed. The signal from the laser sensor is recorded and then analyzed.

Three single faced boards fabricated using mediums 1, 19, and 114 were analyzed for geometry differences caused by the hot and cold corrugating process. The single faced boards were fabricated at a speed of 200 FPM under normal but controlled conditions of web tension and corrugating pressure. The average flute profiles of the cold and hot formed single faced board in Figure A22 show that cold and hot formed flutes are similar in shape. However both cold and hot formed flutes are unsymmetrical and to about the same degree. The unbonded tip is somewhat flattened and rounds-off more gradually to the trailing side than to the drive side. We believe these symmetry differences are related to the different forming conditions for the driven and trailing sides. In addition the dynamic forces imposed in the forming of the bonded and unbonded tips are somewhat different as noted in Figure A5. While the dynamic forces vary in magnitude with corrugator operation it appears that less molding force is applied to the unbonded tip as a result of the drive action.

We also observed in the flat crush test that the unbonded tip collapses first and more rounding-off occurred on the trailing side. This may be due to the above geometry differences.

Figure A22 shows that the cold formed flutes have slightly higher caliper as noted in past studies. There were slight indications that, in two cases, cold

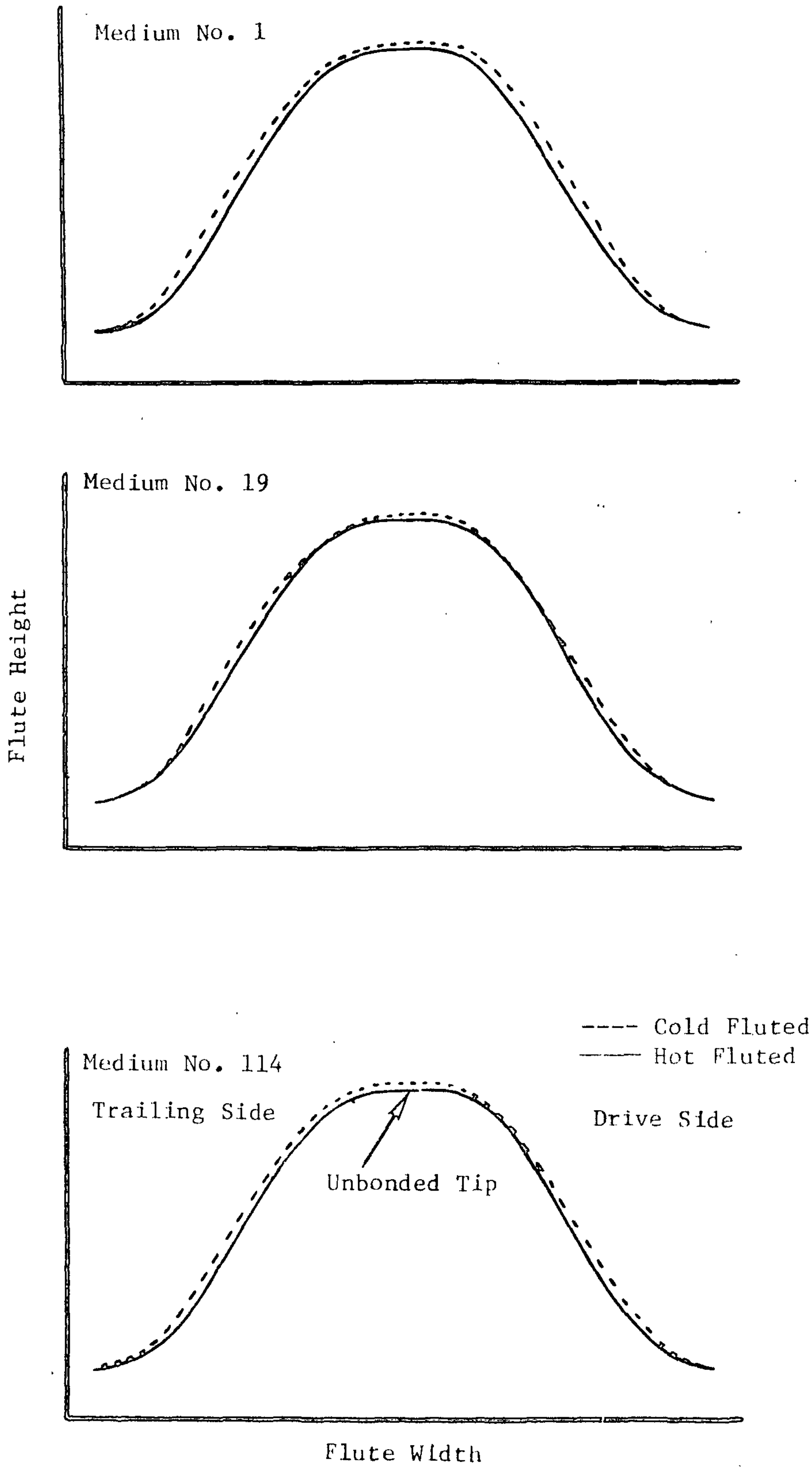


Figure A22. Flute Profile Shapes

formed flutes were more symmetrical in shape; in one case, the hot formed flute was more symmetrical.

The effects of flute geometry on board performance (flat crush, flexural stiffness, short column compression, top-to-bottom compression, etc.) has not been theoretically evaluated as yet. Of particular interest is the flat crush performance. As the hot and cold formed flutes are very similar in geometry, we expect that the differences in flat crush performance between some hot and cold formed mediums are due primarily to differences in the material properties rather than shape.

Mechanics of Flat Crush

One of the specific purposes of our forming research has been to determine why some mediums yield ultimate flat crush strengths which are different for hot and cold forming. In the "Background" discussion we noted that forming conditions appeared to have no major effect up to the first peak of the flat crush load-deformation curve (see Fig. A6, for example). Thus hot and cold formed board should respond similarly to normal converting stresses of the flat crush type.

However, some cold formed mediums exhibit lower ultimate flat crush strengths than under hot conditions as shown in Figure A6. In both cases the mediums deform into a hat-shaped frame (Fig. A11). However, the cold formed medium seems to deform less symmetrically as shown in Figures A10 and A11. In most cases, the second peak in the load-deformation curve (Fig. A6) is absent or only manifests itself as an inflection in the curve if the cold flat crush is low. We found earlier that such cold formed mediums exhibited lower edgewise compressive strength in the flank/tip regions. It appears that the compressive losses affect the formation of the "plastic" hinge points during crushing and the ultimate load.

Flat crush loads are resisted by the flanks of the flute. Figure A23 shows that flat crush loads (expressed as load per unit length of flute side wall) are substantially lower than the STFI compressive strengths of the uncorrugated medium. They are also lower than the compressive strengths exhibited by the formed mediums in the flank/tip regions. While the flank/tip compressive strengths correlate with the flat crush results (Fig. A9), the differences in magnitude in Figure A23 indicate that the mechanism controlling flat crush load-deformation behavior needs to be placed on a sound theoretical basis.

We pursued two approaches concerned with developing a better understanding of the flat crush load-deformation curve. The more fundamental approach was directed to developing a finite element model for the flat crush load-deformation curve. The second approach utilized a simple frame analysis as a conceptual way of explaining various aspects of ultimate flat crush behavior.

Finite Element Analysis. The initial finite element solution allowed for the large deflection behavior of the shell structure. However, as a first step the medium properties were considered to be linear-elastic. This model appeared to provide reasonable estimates of the initial slope of the flat crush curve, particularly when transverse shear effects were considered. This model could not adequately describe flat crush loads beyond the first peak load. Among other things, the results indicated that it would be necessary to account for material nonlinearities as well as large deflection. However, this resulted in a more complex model. To reduce the modeling costs and time, only five elements over a 1/4 flute length were employed. This results in a crude representation of the flute shape (Fig. A24).

Several different kinds of finite elements were needed in the nonlinear structural models. They were an elastic-perfectly plastic hinge, elastic hinge,

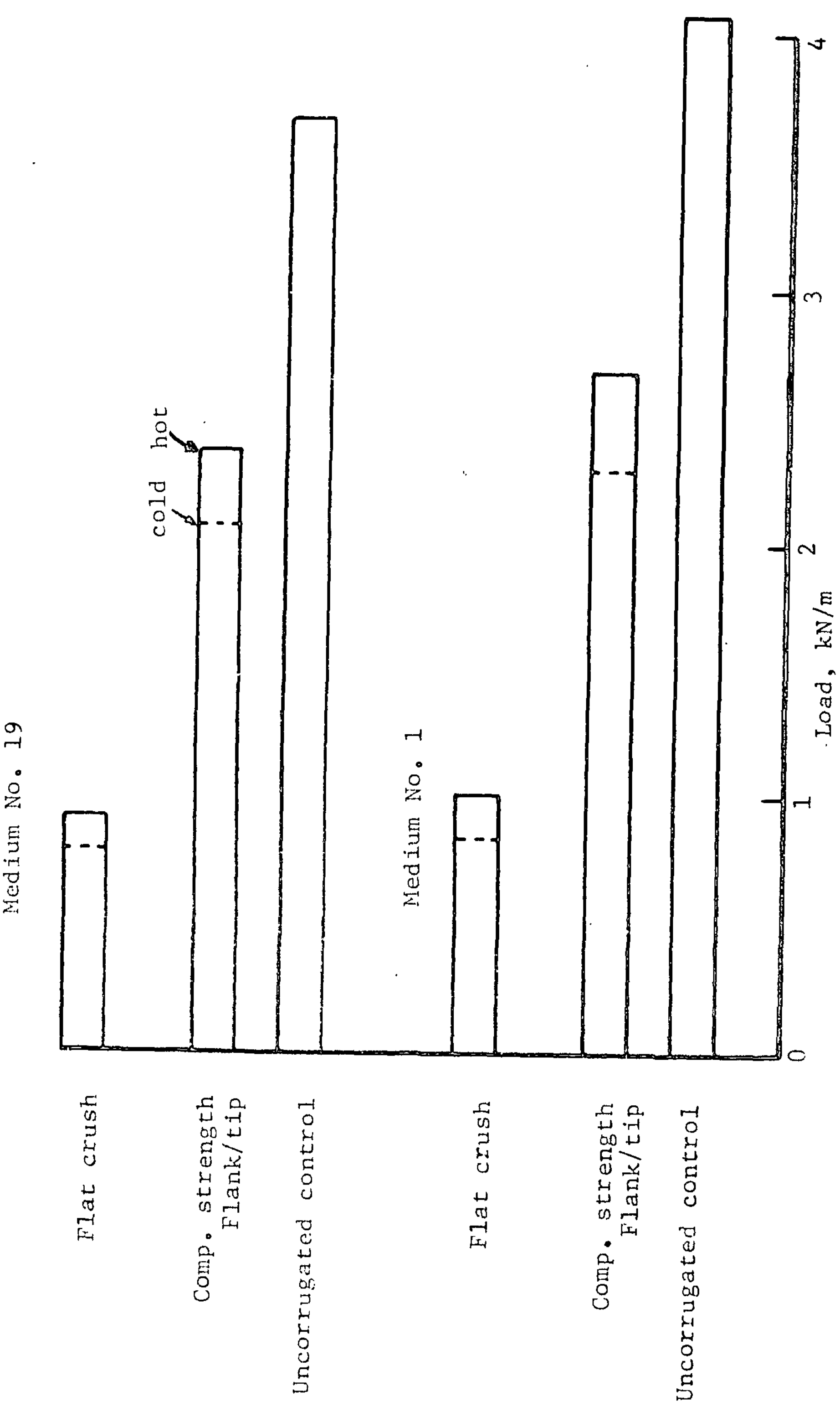


Figure A23. Flat Crush and m.d. Edgewise Compressive Strength Comparisons

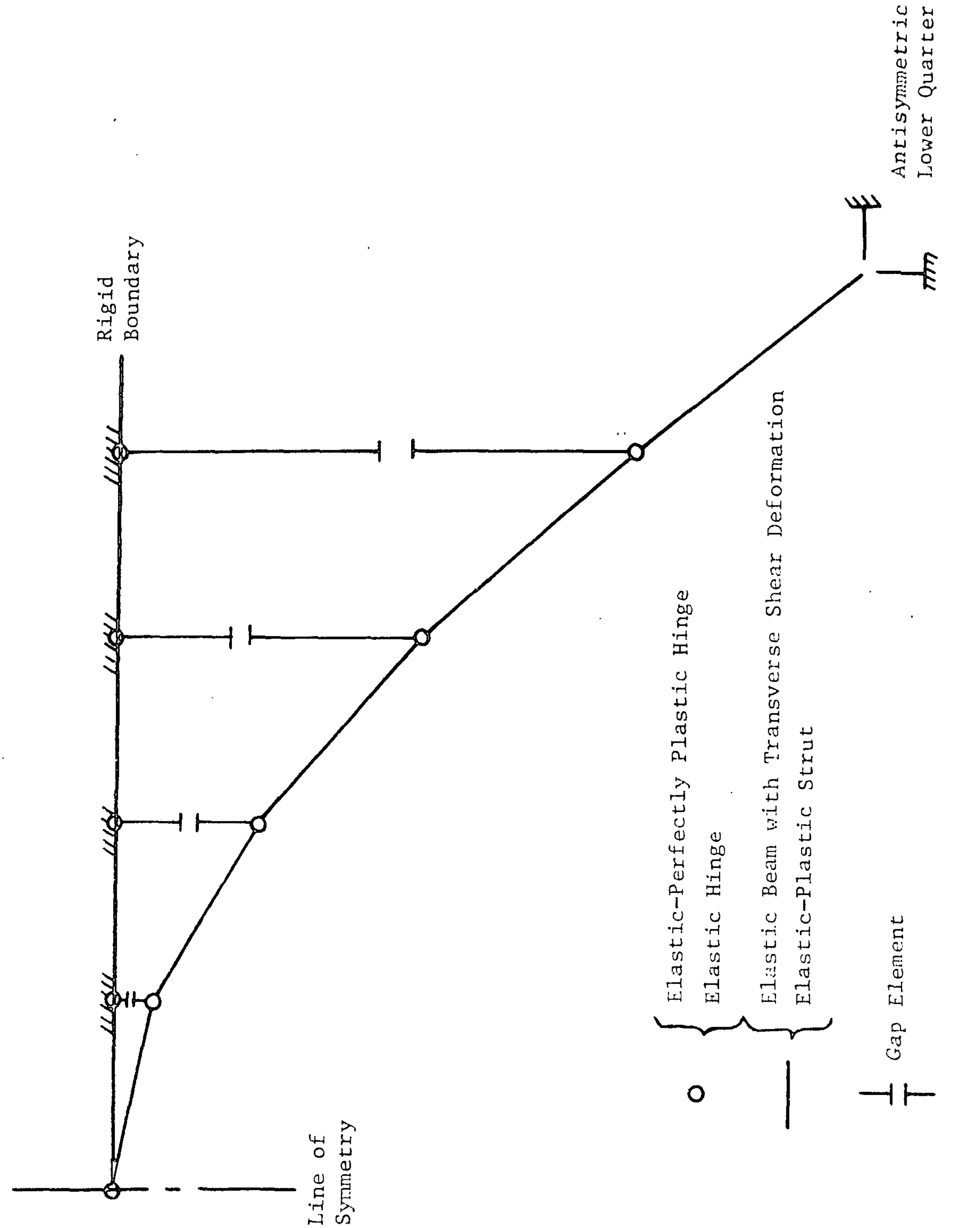


Figure A24. Quarter Symmetric/Antisymmetric Flute Model elastic beam, elastic-plastic strut, and gap element, as shown in Figure A24. We had to utilize several different kinds of finite elements because there was no single finite element available in the element library which incorporated all of the necessary material characteristics that were needed to model paperboard. The elastic-perfectly plastic hinge and the elastic hinge were used to model the bending characteristics of the medium at large rotations. The elastic beam elements were needed to incorporate transverse shear deformation characteristics into the model. The elastic-plastic strut was used to model the in-plane compressive stiffness of the medium. Finally, the gap elements were used to model the effect of the rigid boundary of the liners on the medium shell structure. The characteristics of the elastic-plastic hinge, elastic hinge, elastic beam, and strut were chosen so that compositely they would model the overall material behavior of the medium in a general state of compression. Ideally, it would have been desirable to use a beam element which included all of the necessary material characteristics, i.e., (1) transverse shear; (2) tension/compression; and, (3) nonlinear material behavior.

Nonlinear material properties for compression and tension were experimentally obtained (Fig. A25) at standard test conditions. The compressive properties were used to describe the material response of the strut finite elements. Both the tensile and the compressive stress-strain curves (Fig. A25) were needed to compute the elastic-plastic hinge response (Fig. A26). The solid line is the computed nonlinear hinge response. Since the hinge element could only exhibit elastic-perfectly plastic behavior, the response indicated by the dashed line was used in the structural model. The elastic hinge (Fig. A26) was assumed to have a stiffness of 1 inch-lb/RAD. This value needs to be experimentally confirmed for the large rotational regime.

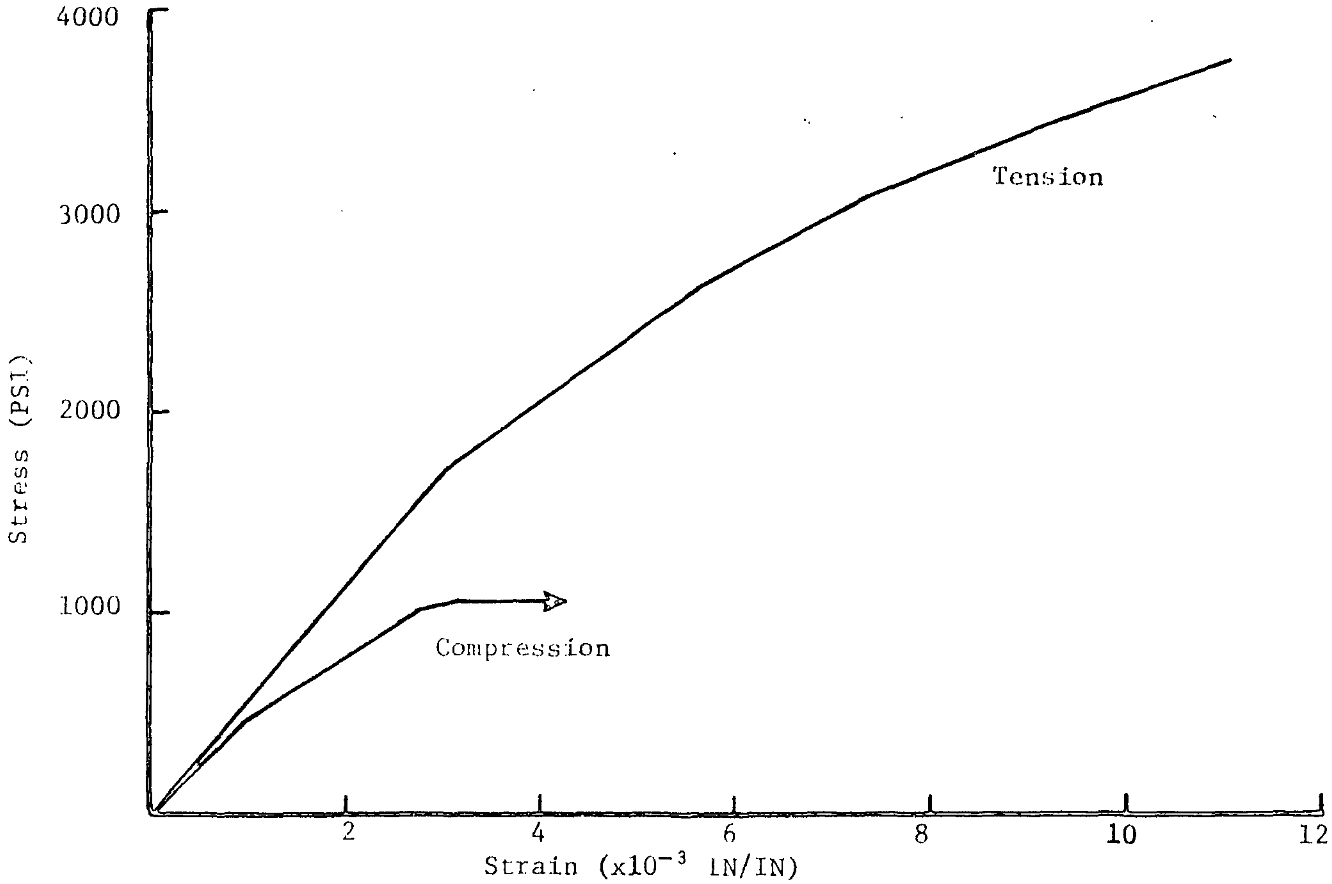


Figure A25. Tensile and Compressive Stress-Strain Curves for the Uncorrugated Medium

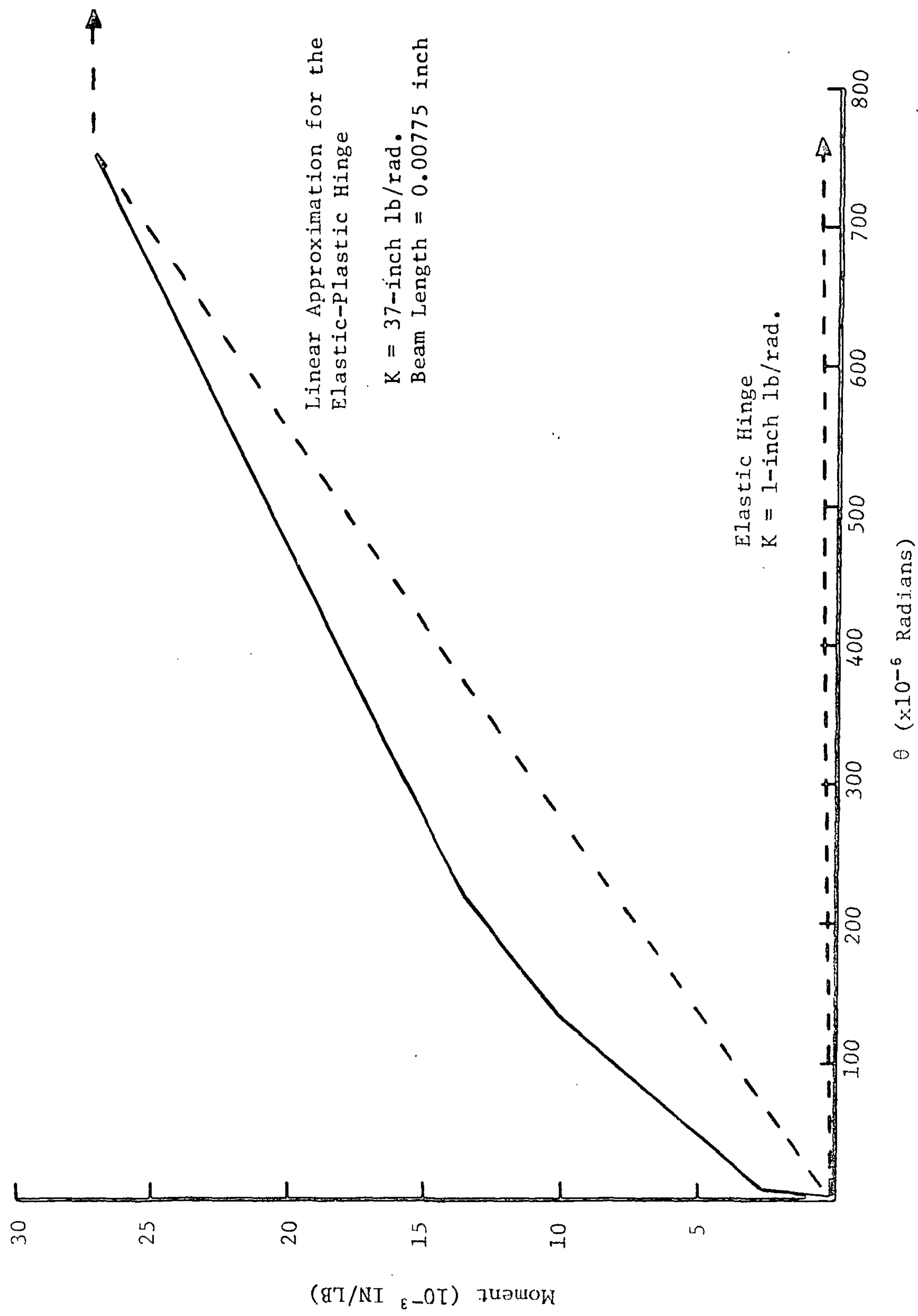


Figure A26. Load-Deflection Response for the Hinges

The predicted large deflection response to flat crush loads of the board after including nonlinearities is compared to the experimental results in Figure A27. We expected that including the material nonlinearities would significantly lower the load-deflection curve relative to the elastic case. This was confirmed as can be seen by comparing the two dashed curves.

The flat crush response is plotted to a larger scale in Figure A28. The general shape of the experimental response curve was captured but the local instabilities (i.e., dips) were not. Possible explanations for this include:

1. Difficulties in evaluating all the material properties needed - e.g., the transverse shear load-deformation curve. Also no allowance was made for changes in properties due to forming.
2. Incomplete material description for large rotational behavior.
3. Incomplete understanding of material nonlinearities related to coupling effects between axial stress, bending stress, and transverse shear.
4. Too few finite elements were used: for this first try, the shell structure was divided up into only five segments.
5. Stress stiffening as well as large deflection may be needed.
6. The large deflection approach used in this particular computer code is too approximate; another code may be needed.
7. Flute geometry was specified to be a perfect sine wave. A nonsymmetric nonideal flute profile may be needed as described in the flute geometry section.

Another aspect observed in the experiment that was not captured by the finite element model is the almost complete vertical straightening of the flute sides during flat crush. The predicted flute profiles show no pronounced tendency toward

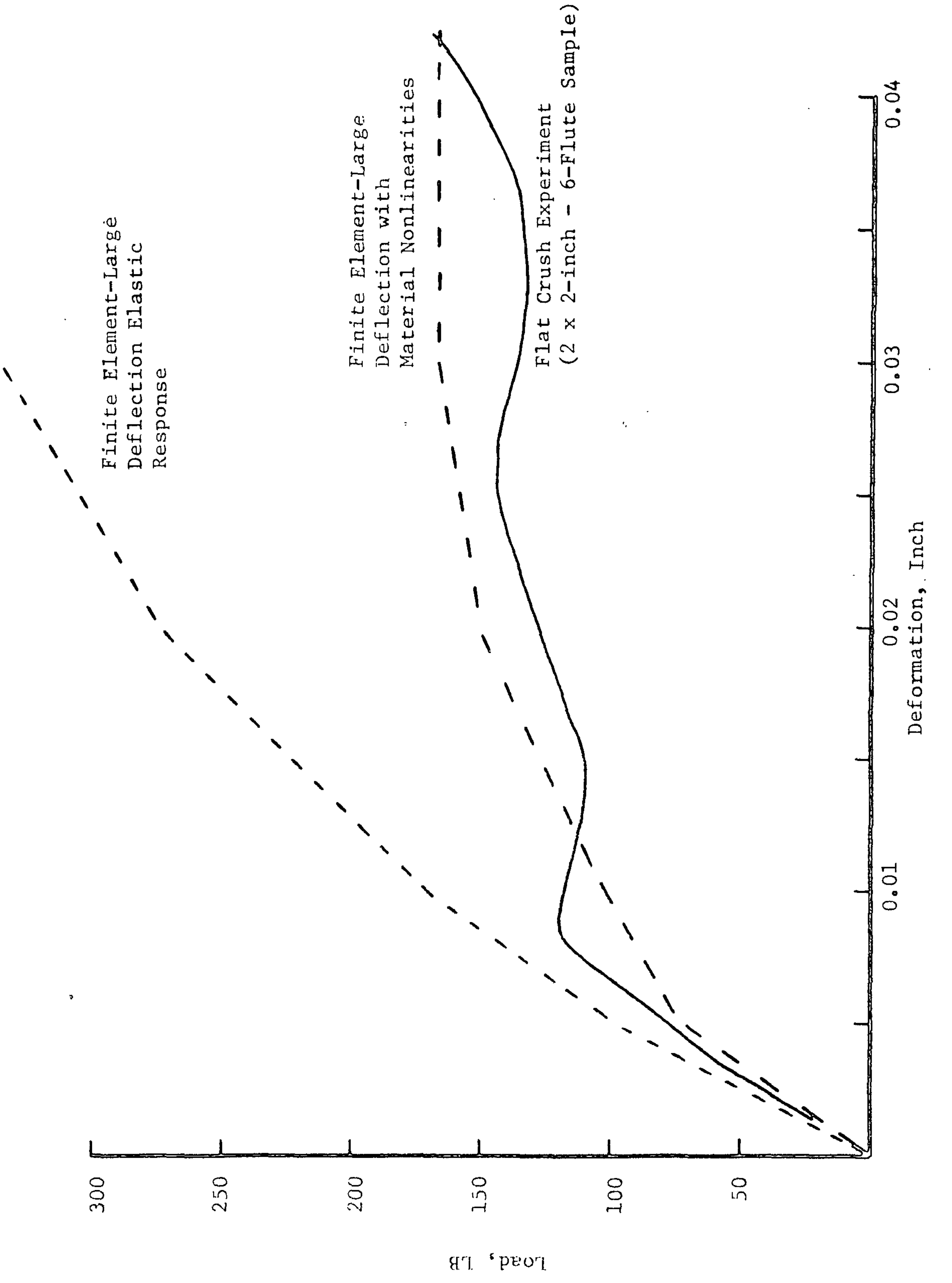


Figure A27. Elastic and Nonlinear Model Load-Deflection Responses for Flat Crush

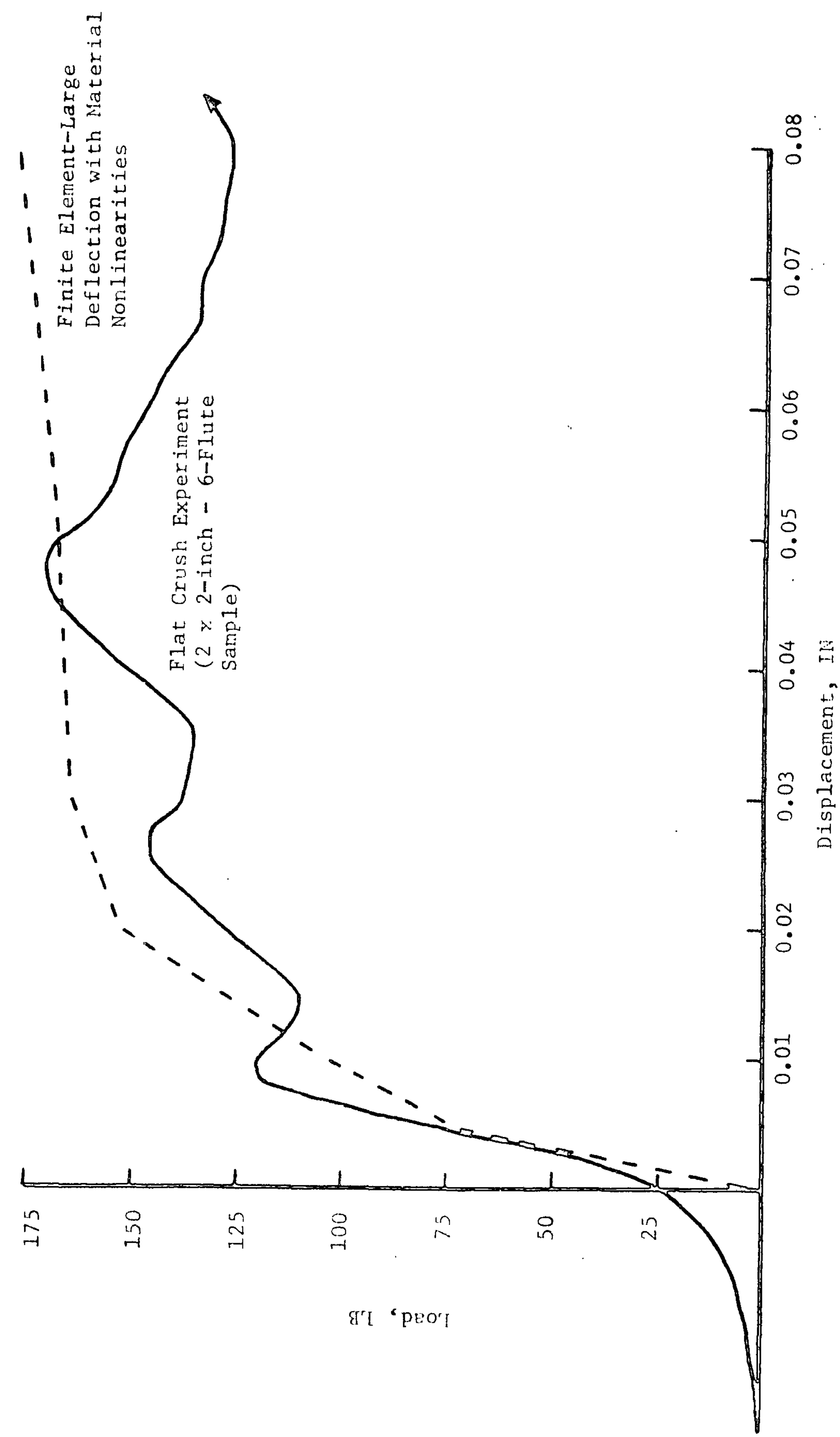


Figure A28. Predicted and Measured Load-Deflection Responses for Flat Crush this vertical straightening (Fig. A29). However, the simpler linear-elastic, large deflection model captured the vertical straightening (Fig. A30). Note that the deflected shape approximates the observed hat shape of the medium near failure. Currently, we do not know if this difference in behavior is a result of the simplified finite element model (only 5 elements per 1/4 flute), or the material property assumptions.

We believe that Figures A28 and A30 illustrate the potential ability of finite element models to predict the entire flat crush load-deformation curve. Such models would allow us to better define the characteristics of the medium which govern not only flat crush failure but also the initial load behavior so important in converting. However, the full potentials of finite element analysis cannot be realized until better methods are developed to evaluate the physical properties of medium and board. For this reason further work on this model has been stopped pending the development of better material models in fundamental studies at the Institute.

Frame Analysis. In the final stages of the flat crush test the medium forms a frame-shaped structure (Fig. A31). Timoshenko (36) discusses a frame buckling case which is somewhat similar to flat crush. This results in an Euler type column equation where the end-condition coefficient depends on the thickness of the medium and the frame dimensions. Thus, $P = k^2 E I/\ell^2 = k^2 Et (t/\ell)^2$

where P = maximum load,

E = modulus of elasticity in direction of load,

I = moment of inertia, $= wt^3/12$,

w = column width,

t = thickness,

ℓ = frame height, and

k^2 = frame coefficient dependent on the lengths of the elements and moments of inertia (I, and I_1, in Fig. 31).

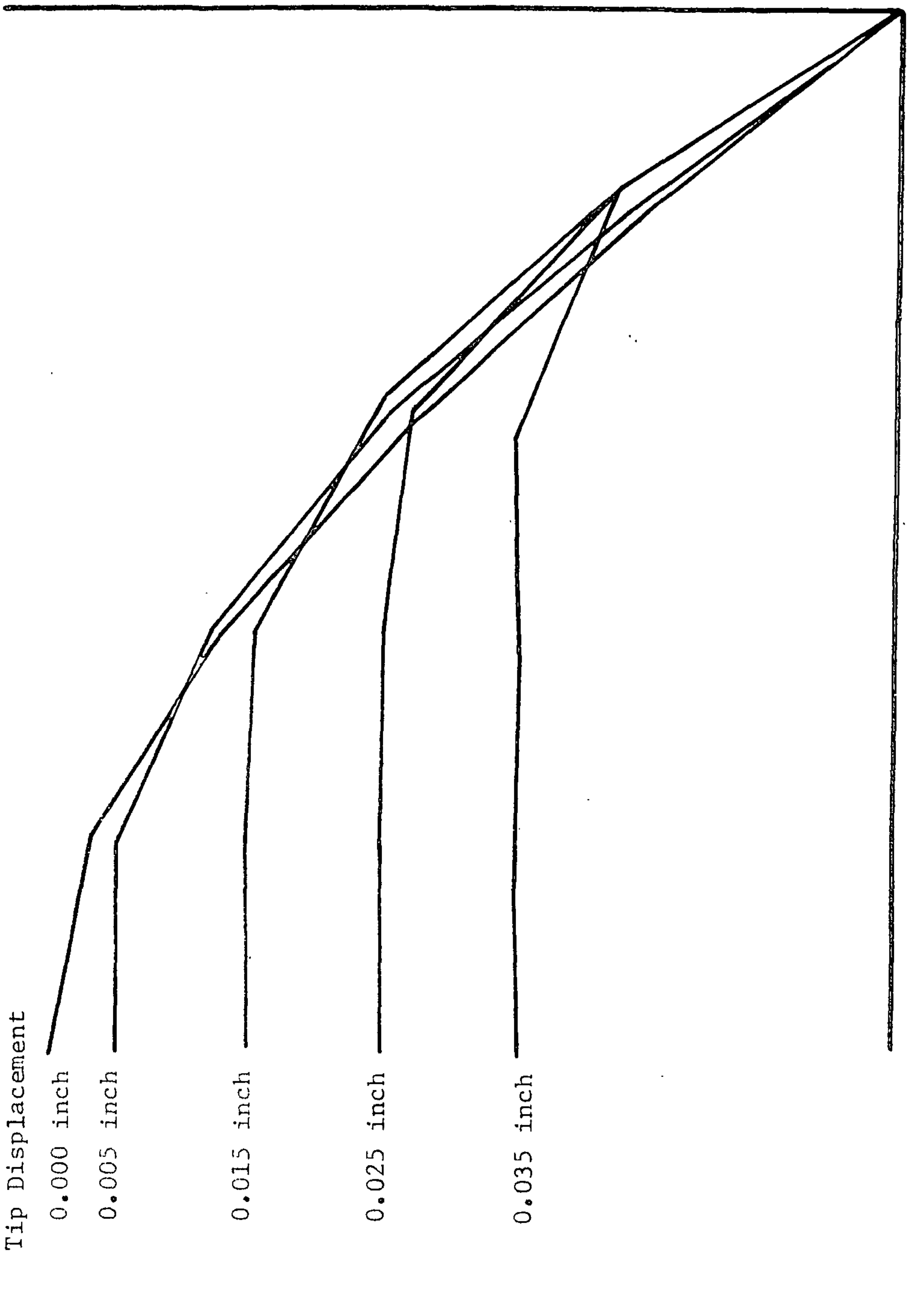


Figure A29. Deflected Flute Profiles for Quarter Flute Model Allowing Large Deflections and Material Nonlinearities in Analysis

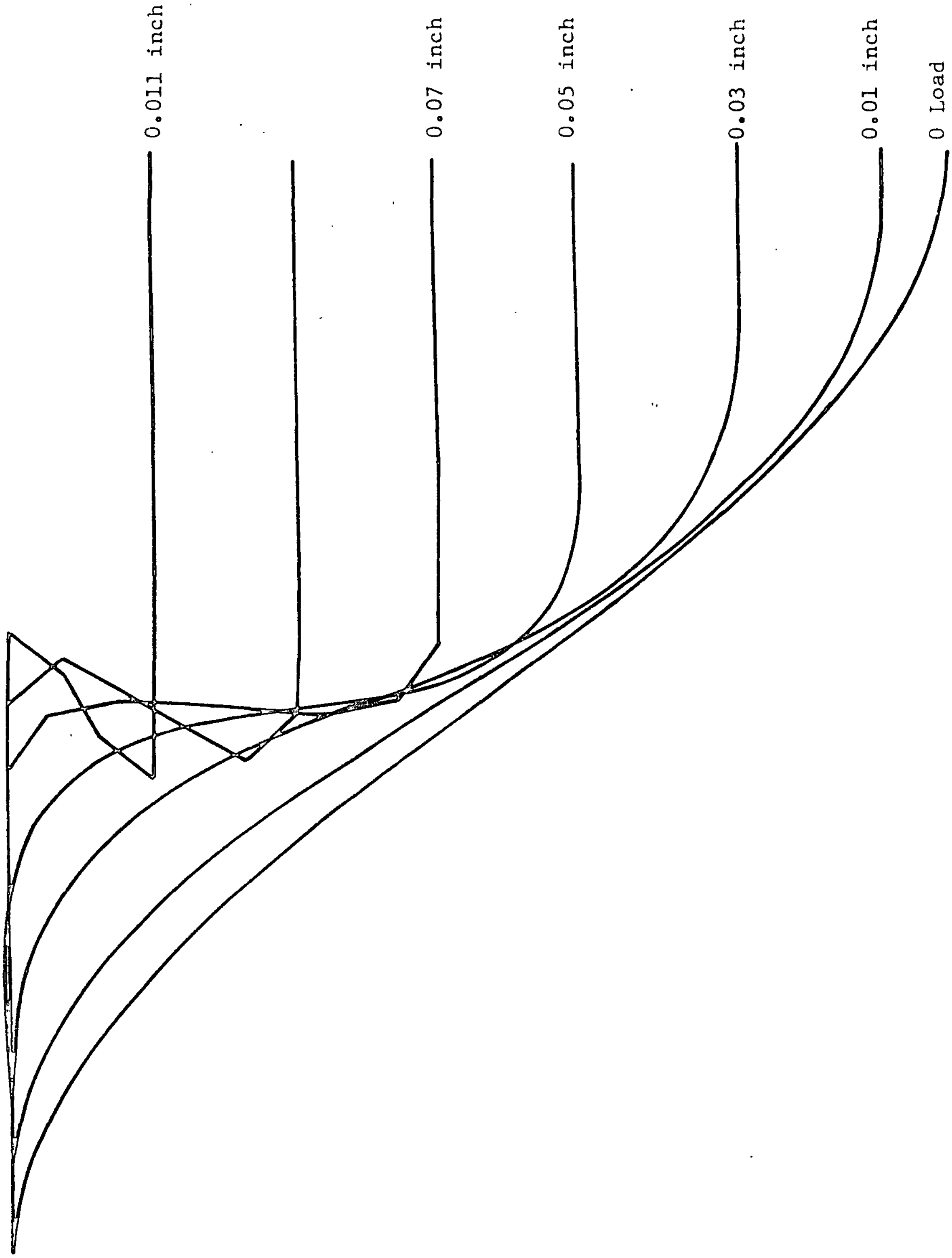


Figure A30. Deflected Flute Profiles for Half-Flute (Large Deflection, Linear Elastic Model)

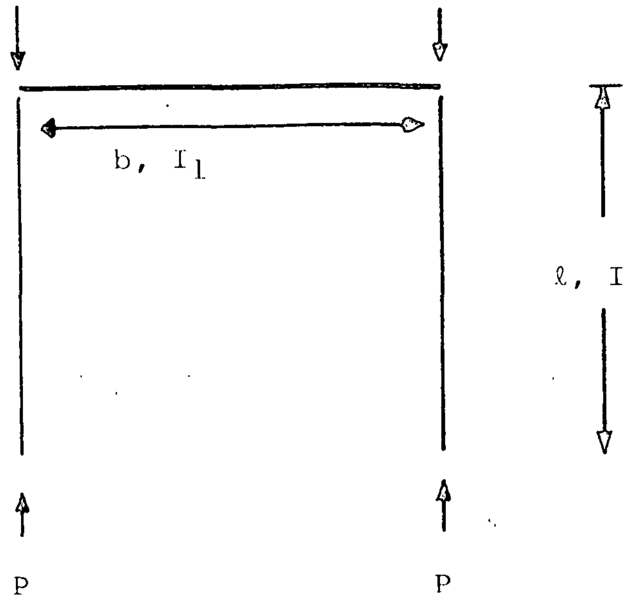


Figure A31. Frame Buckling - Lateral Displacements Permitted

The frame equation provides a conceptual way to explain such effects as flute geometry, the weight or thickness of the medium and various papermaking factors. Brecht and Bachmayer (34) in an extensive investigation showed that "generally everything which increases the elastic modulus" increases Concora strength. Their work was carried out on hot formed medium but we believe cold formed mediums will respond in a similar way to many of the papermaking conditions studied. They also noted that hot Concora strength was quite sensitive to thickness. They cited the following: (1) Concora may not be greatly affected by wet pressing if the increases in modulus are counterbalanced by the decreases in thickness; (2) dry pressing can reduce Concora because the reductions in thickness are not compensated by real increases in fiber-to-fiber bonding; and, (3) increasing the fiber orientation increases the elastic modulus and Concora in the m.d. direction. Brecht and Bachmayer proposed an empirical modification of Eq. (1) which related Concora to the modulus, basis weight, and the square of the thickness. The relationship explained the general trends but there was considerable scatter indicating other factors are involved.

There are theoretical and measurement difficulties in directly applying the frame analysis approach. Among the measurement factors are the determination of (1) effective caliper, and (2) modulus after forming. Theoretical difficulties involve allowance for inelastic and/or shear affects, proper evaluation of end conditions, etc.

With these reservations, Figure A32 shows preliminary frame equation estimates for medium sample 1 in comparison to flat crush and compressive strength. The frame loads are close to the flat crush magnitudes at reasonable frame heights - i.e., 0.060 to 0.075 inch (about 1.5-2.0 mm). They do not necessarily explain cold/hot flat crush differences because it is not possible at present to obtain Et values after forming.

The buckling coefficients in Figure A32 were based on dimensions scaled from test photographs. There is an indication that hot-formed board has higher k^2 values than cold formed board. This would promote higher flat crush for the hot board.

It is believed the frame equations provide a conceptual way to explain the effects of variables such as flute geometry, medium thickness or weight, etc. on flat crush. However, to explain differences in flat crush due to forming conditions would require adjustment of either the geometrical or material properties in whatever theoretical approach is pursued.

In this connection 34 commercial mediums were fabricated into single-faced board on the Institute's experimental corrugator. Both cold and hot cor-

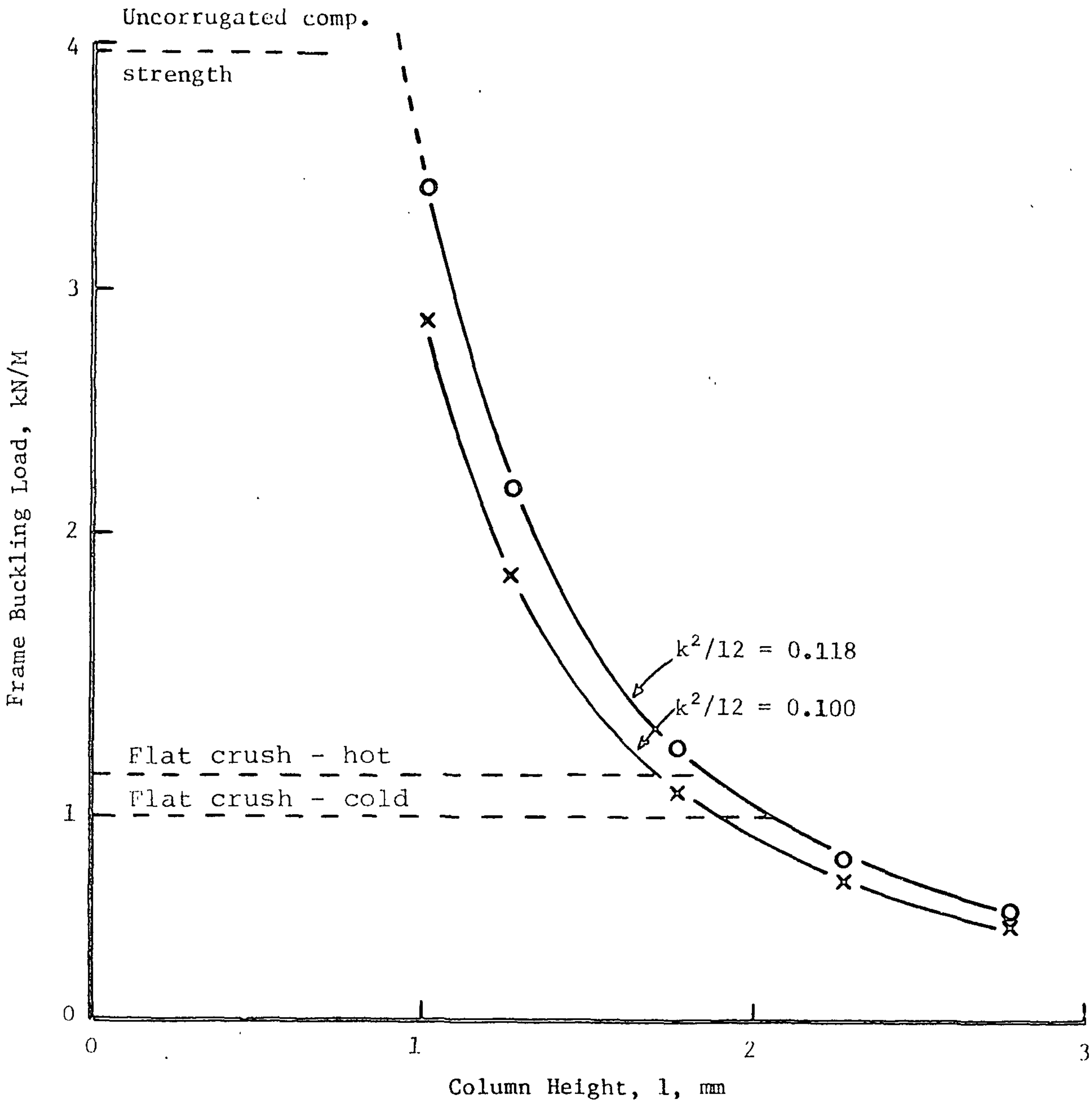


Figure A32. Frame Results for Various Column Heights at Constant Length to Width Ratios rugating conditions were employed and the single-faced boards obtained at 600 FPM were evaluated for flat crush. The uncorrugated mediums were evaluated for a wide array of physical properties. The correlations between the uncorrugated medium properties and flat crush are summarized in Table III.

TABLE III
FLAT CRUSH *vs* VARIOUS MEDIUM PROPERTIES
- 34 MEDIUM SAMPLES -

Property	Correlation Coefficient: Hot Flat Crush	Correlation Coefficient: Cold Flat Crush (WTA)
Basis Weight	0.21	0.34[a]
Caliper	0.07	0.12
Density	0.08	0.09
Moisture Content, cond.	0.19	0.25
Moisture Content, uncond.	0.03	0.19
Porosity	-0.25	-0.21
Smoothness	0.08	0.06
Friction, F.S. (cold)	0.11	0.46[b]
Friction, W.S. (cold)	0.18	0.49[b]
Concora	0.94[b]	0.60[b]
Mullen	0.42[a]	0.28
CD Ring	0.59[b]	0.51[b]
MD Tensile	0.60[b]	0.47[b]
MD Stretch	0.32	0.16
MD TEA	0.46[b]	0.37[a]
MD Stretch	0.42[a]	0.41[a]

[a]Significant at 0.05 level.
[b]Significant at 0.01 level.

Under hot corrugating conditions the Concora (hot forming) results were highly correlated to flat crush as would be expected. However, the Concora correlation declined from 0.94 for hot corrugating to 0.60 for cold corrugating. Thus the Concora test which is based on a hot fluting action is well correlated to hot corrugating but not to cold corrugating.

Some of the other properties were correlated to flat crush but the correlations were not very strong.

Summary

Our research has focused on several areas. They include the effects of hot and cold conditions on (1) fluted medium characteristics, (2) flute geometry, (3) flat crush load-deflection behavior and (4) the effect of various forming stresses on the compressive strength of the fluted medium.

Our results indicate that edgewise compressive strength and other properties of the medium are greatly reduced by both forming processes. The reductions in medium strength are substantial and affect the quality of combined board to about the same extent under either cold or hot corrugating conditions. The reductions in strength are caused by the high bending and tension stresses induced in the medium during forming. For some mediums the strength reductions are somewhat more severe under cold corrugating conditions and this reduces the ultimate flat crush strength. However, the initial flat crush load-deflection behavior is the same for both cold and hot forming, only the failure loads are different, therefore cold and hot formed boards should respond in the same way to normal converting. Furthermore, the strength reductions caused by both forming processes are much more important as a subject for study than are the differences in strength between hot and cold formed structures.

Specific findings are noted below.

(1) The edgewise compressive strength of the fluted medium (cold or hot formed) is reduced in both m.d. and c.d. directions. The reductions range from 35-50% in the m.d. direction. The c.d. compressive strengths are reduced by about 20-30%. These findings are significant because they indicate that the fluting process degrades the compressive strength potentials of the medium in both directions. Thus box compressive strength, flat crush strength, and other combined board properties are all reduced.

(2) Some cold formed mediums show more evidence of compressive strength reduction in the flank/tip regions than under hot conditions. We believe this accounts for the lower flat crush obtained with some cold formed mediums. It was also noted that such cold formed mediums tend to exhibit more compression degradation on the trailing flank than on the driven flank.

(3) The transverse bonding strength of the medium is also reduced by forming in both the cold and hot processes. The reductions in bonding would be expected to reduce the compressive strength and other properties of the formed medium.

(4) In simulation experiments, we observed that prestressing the medium in bending reduces edgewise compressive strength. Our results also show that the compressive losses are increased by higher tensions during bending. As expected, greater losses occur as the radius of bend decreases because the strain in the outer fiber layers is inversely related to the radius. These results suggest that the compressive strength losses - and hence the flat crush losses - are due primarily to bending stresses induced during forming.

(5) Analysis of clearances in the labyrinth shows that a potential pinch point exists about 1/2 flute ahead of the center line. In past work at the Institute, high speed motion photography shows that fracturing occurs before the medium reaches the center line - also by about 1/2 flute. If the medium cannot freely slide past the "pinch point" it will be strained more highly and this will increase the risk of fracture or cause greater reductions in strength of the medium. Drives for both corrugating rolls (dual drives) have been tried at at the Institute and elsewhere in the past to minimize clearance problems and improve fluting. However, in limited trials dual drives have not appeared to produce marked improvements in fluting performance.

(6) When the medium is formed around the flute tip the severe bending stresses are relieved by the simultaneous shear strains. Exploratory evaluations indicate the m.d. transverse shear modulus of medium is 30-40 times lower than the m.d. extensional modulus. Because of the low shear modulus, shear effects can be an important factor in allowing the medium to conform to the fluted contour. Because the shear characteristics of the medium are important in corrugating, one aspect of future work should be the development of methods for evaluating and controlling this property. We would then be able to account for both bending and shear effects in corrugating and other forming operations in board conversion.

(7) A thorough review of flat crush technology was carried out. It appears that the initial portion of the flat crush load-deformation curve is critical in determining whether crushing in finishing will degrade board quality. However, the entire load curve is important because field performance depends on crush resistance up to ultimate failure.

Our observations indicate that cold and hot formed board exhibit about the same performance up to the first peak of the load-deformation curve. Thus cold and hot formed board should perform equally well in converting and end-use so long as the stresses are not materially greater than the initial peak load.

(8) Detailed analyses of hot and cold formed board indicate there are only small differences in profile shape. Thus, differences in the ultimate flat crush performance between hot and cold formed board are due to fluted medium characteristics rather than flute geometry.

(9) We also carried out a preliminary mechanics analysis of flat crush load-deflection behavior using finite element techniques. The finite element

models appear to predict the general load response of the flute. The models also show promise of predicting the deflected shape as loading progresses. Among other things the initial results suggested that the shear characteristics of the medium may be of importance. However, the full power of finite element modeling cannot be brought to bear until we have completed development of methods of evaluating medium properties.

ADHESIVE DEVELOPMENT

Introduction

Cold corrugating requires an inexpensive adhesive that develops proper bonds with little or no heating of the components. Early work on such adhesives, initiated in the early 70's, identified thermo-chemically modified pearl starches as prime candidates for this application. Concerted efforts at developing this adhesive, started in the mid-70's, used simple cookers and devoted attention primarily to single face bonding. Pilot work, started in 1978, provided the first evidence of the double face bonding properties of the modified pearl starch adhesives. It was immediately clear that the DF bond requirements were more demanding than the SF bond requirements.

Over the intervening years much effort has been devoted to developing workable adhesives with rapid bonding properties for the DF bond. Along the way, the double backer simulator was developed as a sophisticated tool for quantitative evaluation of the DF bonding process. Most of the adhesive formulation work has been empirical and experimental in nature and has been directed to the chemical aspects of the conversion process and the finished adhesive. Simulator results have been used to guide setting of other combining parameters to yield the best overall performance of the bonding system. Much of this work and the background related to thermo-chemically converted pearl starch adhesives was presented in the last progress report (4).

Over the past year most of the work in the bonding area has been based on use of the simulator and the pilot double backer to achieve the best possible double face (DF) bonding performance. This bonding process is influenced by four factors; the adhesive, adhesive application (amount and distribution), the combining conditions and the properties and state of the components. To optimize this system adhesive performance was mapped as a function of the formulation variables. These data were then used to guide experiments to determine the best selection of the other bonding system factors. Due consideration was given to interactive effects. Results obtained from the simulator in this way were then used to guide pilot trials to confirm the general directions of the improved process. A brief summary of the results of these various development experiments is given below.

Adhesive Formulation Development

Conversion Conditions

The major formulation variables (slurry solids, ammonium persulfate (AP), cooking temperature, pH) and their relation to bonding rate and operating parameters have been thoroughly explored. Figure A33 shows a summary of these results presented in terms of bond strength after 8 seconds*. Fastest bonding is generally obtained at the highest workable solids (about 39%), at conversion levels permitting good flow in the applicator system (viscosities of about 300-400 BU) and at cooking temperatures which cause full dispersion of the starch.

Molecular Weight Distributions

In a further effort to improve bonding rates we have tried to modify the molecular shape and size distribution of the starch in the adhesive. In general for starch adhesives, higher molecular weights give stronger bonds whereas raising solids requires lowering molecular weights to achieve comparable viscosities. A highly modified starch containing a portion of a high molecular weight starch should give improved strength while retaining proper viscosity and rapid bonding rate.

* Good performance at commercial speeds requires the development of a strong bond within 8 seconds.

8 SECOND BOND

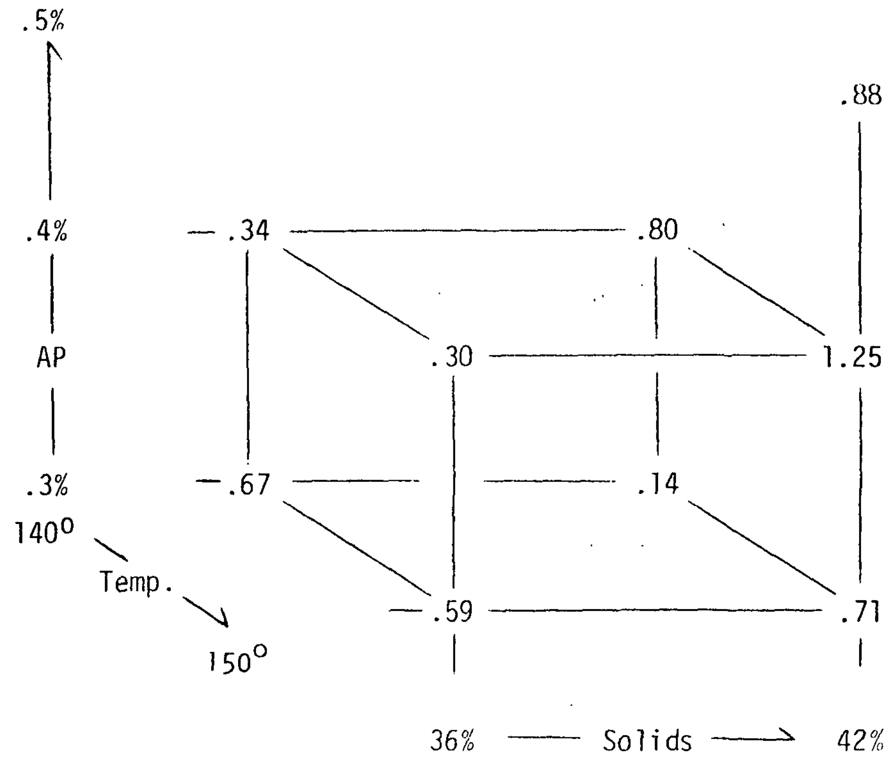


Figure A33. Bond Strength After 8-Seconds as a Function of Formulation Variables

Such a hybrid starch adhesive was produced in two ways. One was prepared by the technique of AP hold out, a method of modifying a portion of the starch in an adhesive preparation differently from the rest. In this method, conversion of a starch slurry was started with little or no AP. After an appropriate interval of time AP was added to the remaining slurry to give the required degree of modification. In the second method, pearl starch was combined before cooking with a highly modified dextrin. This combination gives a bimodal molecular weight distribution both before and after cooking. Typical results from this work are shown in Table IV. These data reveal no significant improvements in either bonding rate or final bond strength (pin adhesion values).

TABLE IV

MODIFICATION OF STARCH MOLECULAR SIZE AND SHAPE DISTRIBUTION

Cook	Starch	AP %	Slurry Solids, %	Cook Temp., °C	Viscosity BU	Bond 8 Sec.	Strength 10 Sec.	Pin Adhesion
1201	Pearl	0.4	41.8	150	330	1.14	1.70	76
2403	Pearl	0.4[1]	41.6	150	300	1.37	1.73	77
0901	Pearl	0.3	35.7	141	310	.89	1.37	77
2601	1/3 Pearl 2/3 High Fluidity	0.1[2]	36.3	140	430	.80	1.17	88
2901	Pearl	0.4	41.8	150	360	.93	1.49	79
0601	3/4 Pearl 1/4 Amylopectin	0.3[3]	41.6	150	395	1.17	1.68	83

1. After 1 minute.

2. AP is equivalent to 0.3% on pearl starch.

3. AP is equivalent to 0.4% on pearl starch.

A similar effort to improve adhesive performance by modifying the molecular composition was made by varying the amylose to amylopectin ratio. Starches high in amylose or amylopectin were used in combination with pearl starch. These results are also shown in Table IV. Although gains in bond rate were sometimes observed with amylopectin/pearl blends, straight amylopectin gave poorer bond rates. Increasing the amylose content did not strongly affect the bonding rate.

Water Resistance

When amylose starches are substituted for the pearl starch a good level of water resistance is obtained in the adhesive bond (4). These starches require cooking at 160°C. Wet strength type resins have also been used both with high amylose and modified pearl starch but with only limited success.

Cross-Linking

Several other modifications to the adhesive formula were made in an effort to improve bonding. Addition of the cross-linking agent, glyoxal, gave better pin adhesion tests but poorer bond rates. The addition of glycol to the final adhesive to act as a wetting agent did not significantly improve the bonding rate. Addition of the more powerful wetting agent, Surfynol, reduced the bonding rate and, perhaps, the pin adhesions too.

Grafting

Modification of the starch by graft copolymerization of itaconic and acrylic acid* during cooking gave improvements in bond rate but the results were confounded by increases in viscosity. Figure A34 shows that a lower solids, grafted adhesive, Curve B, gave almost the same bond rate as an ungrafted adhesive

* The hazardous nature of acrylic acid is recognized.

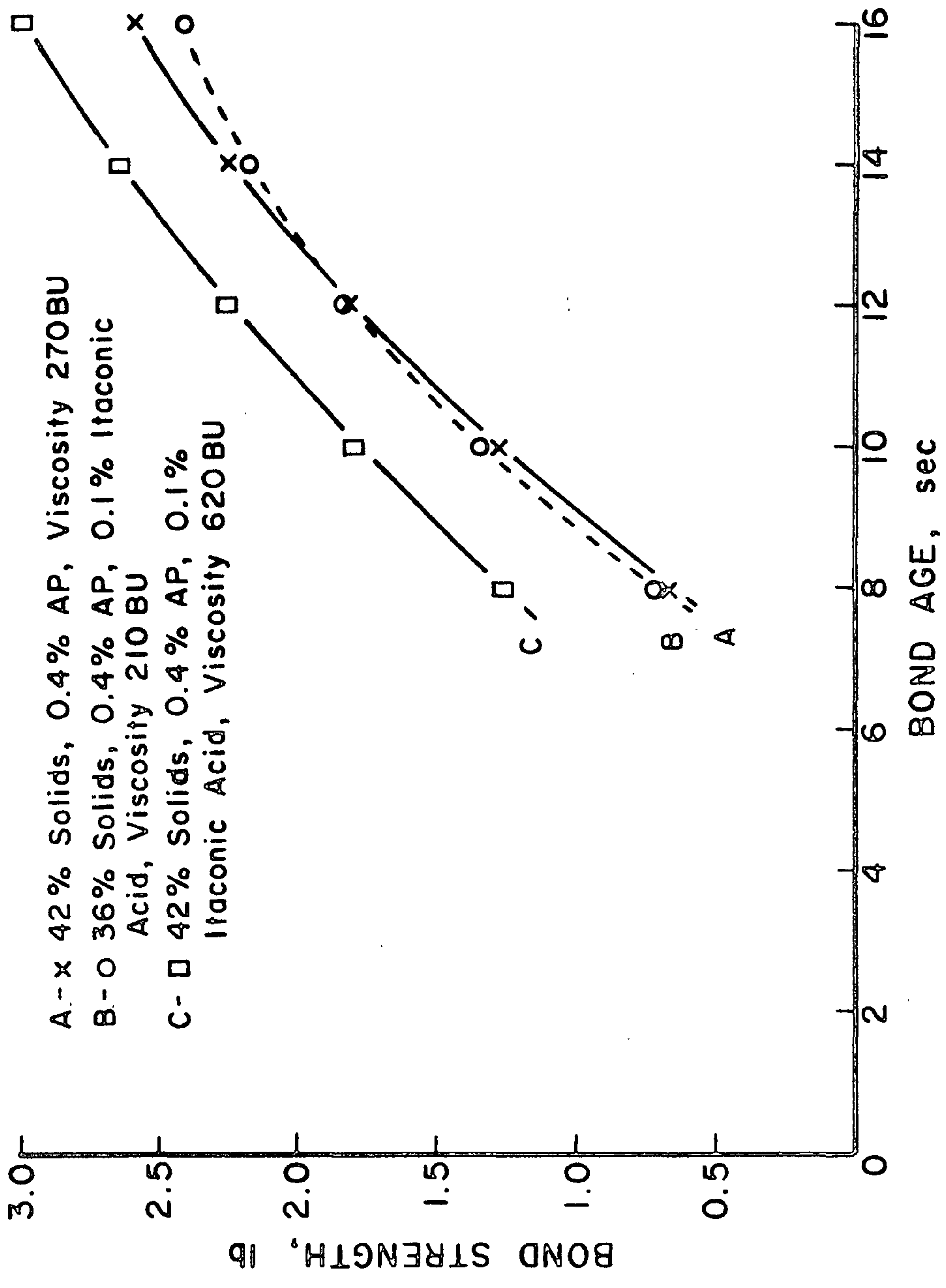


Figure A34. Effect of Itaconic Acid Grafts on Bond Rate at higher solids, Curve A. Grafted adhesive at high solids, Curve C, showed improved bond rate but at considerably increased viscosity. This is one area of exploration where more work is justified.

Adhesive Application

Simulator tests have repeatedly shown the importance of proper adhesive application both in terms of amount and distribution. Bond formation with aqueous adhesives employed under cold corrugating conditions depends on both cooling and drying of the adhesive with drying being the more important. As a consequence rapid bond development requires maximizing drying rate and minimizing water added. Adhesive distribution affects drying rate; adhesive application rate (for a given adhesive solids level) determines the amount of water added.

Adhesives are normally applied to the flute tips of corrugated board from some type of roll. The surface characteristics of the roll are very important in determining the distribution of the adhesive on the flute tip. Figure A35 shows three bond development curves, each for an adhesive application rate of about 0.7 lb/MSF, and all for otherwise identical conditions. Clearly the fastest bond development is obtained with the small cell (25 quad) gravure roll. For this roll surface the adhesive is distributed over the flute tip in a fairly uniform fashion. This maximizes the area available for transport of water for each unit of adhesive applied. The 16 quad roll tends to distribute the adhesive over the flute tipe but in fairly large individual globules. This reduces the uniformity of coverage and the specific area available for transport. Direct contact between a flute tip and a smooth roll squeezes the adhesive onto the shoulders of the tip giving both poor distirbution and a small specific area for transport. These data suggest that uniform distribution over the flute tip will give fastest bonding. Final bond strength is less sensitive to these distribution characteristics as indicated by the data in Figure A35.

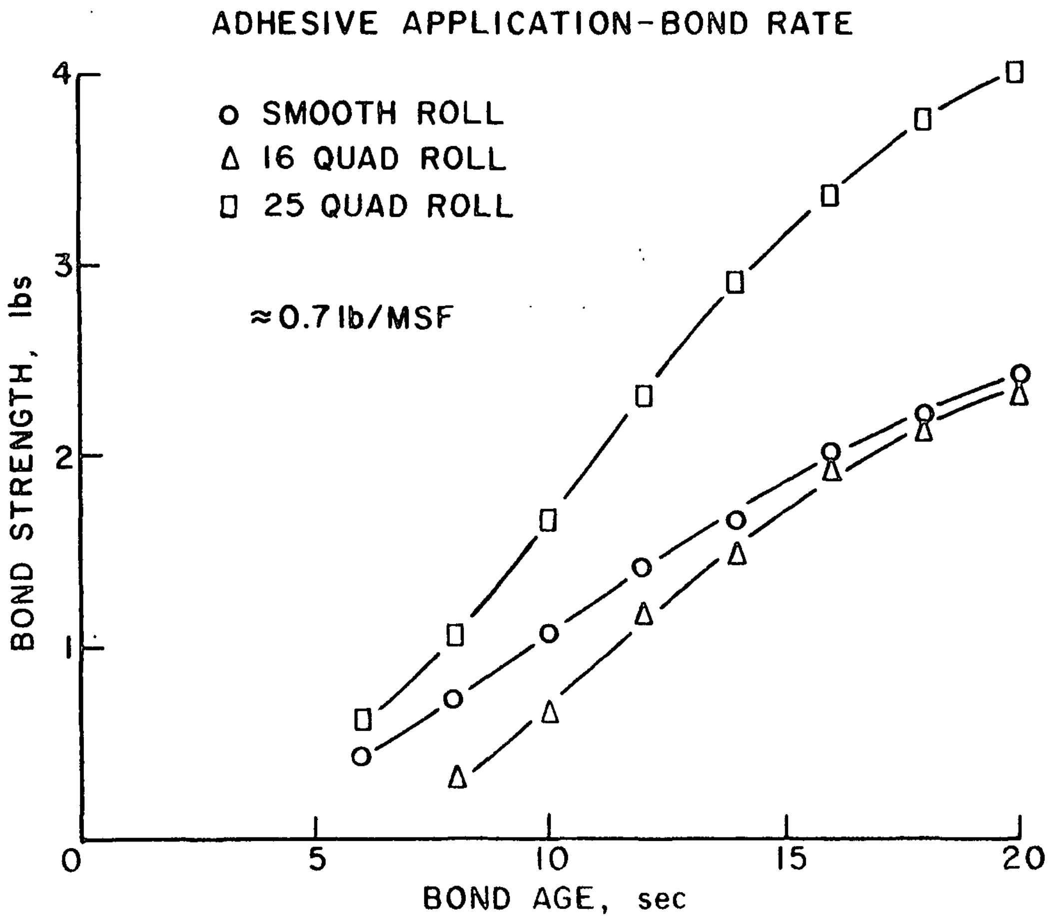

ADHESIVE APPLICATION-BOND RATE
o SMOOTH ROLL
Δ 16 QUAD ROLL
□ 25 QUAD ROLL
≈0.7 lb/MSF
BOND STRENGTH, lbs
4
3
2
1
0
5
10
15
20
BOND AGE, sec

Figure A35.

For a given adhesive distribution pattern bonding rate varies inversely with application rate. This is illustrated quantitatively in Figure A36. For the ideal combining environment provided by the simulator excellent bonds can be achieved with about 0.5# of adhesive (solids) per MSF. The less certain, more dynamic combining environment in a real machine coupled with less precise application requires higher application rates for production. Nevertheless, the clear message is to use the minimum amount of adhesive consistent with real operating conditions and spread the adhesive uniformly over the flute tip.

Component Treatments

On the basis of studies of the operating variables for the Double Backer Simulator, several efforts were made to improve bond rate by pretreating the liner board.

Earlier work indicated that increasing liner moisture reduced bonding rate while heating the liner increased it. These results were reaffirmed in the laboratory and in mill trials. Mild chemical modification of the liner surface was attempted by treating it with various dilute solutions and drying prior to bonding. All of these treatments caused some improvement in bond rate. Moreover, the same treatment using distilled water caused a similar improvement. The nature of the chemical did not appear to affect the bonding rate significantly even though it did affect the surface sizing of the liner. The application of heat to the treated liner just prior to bond formation improved the bond rate over that of the unheated, treated liner (Fig. A37). It appears that the effects of heating and liner pretreatment are additive.

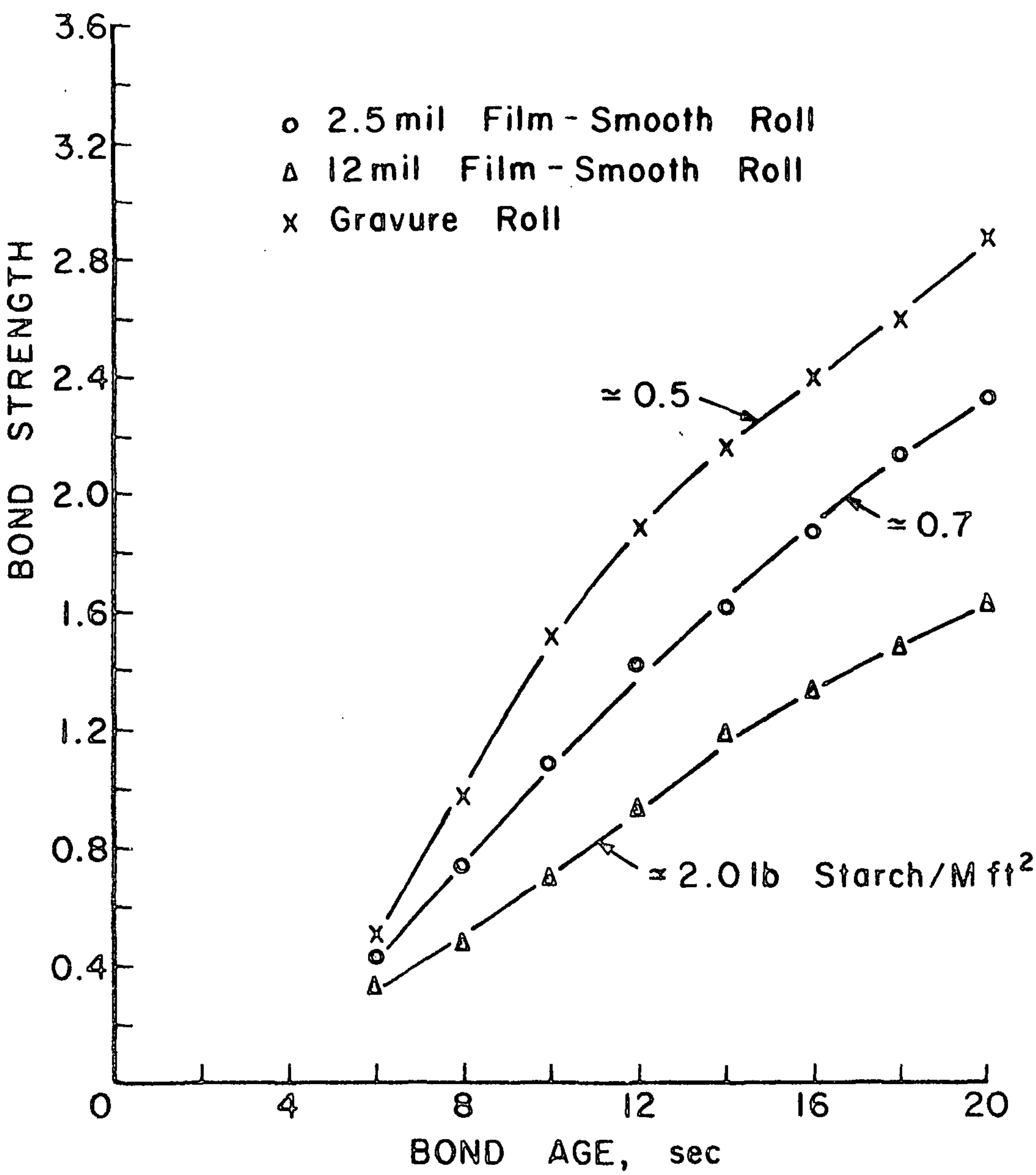


Figure A36. Effect of Adhesive Metering on Bond Development

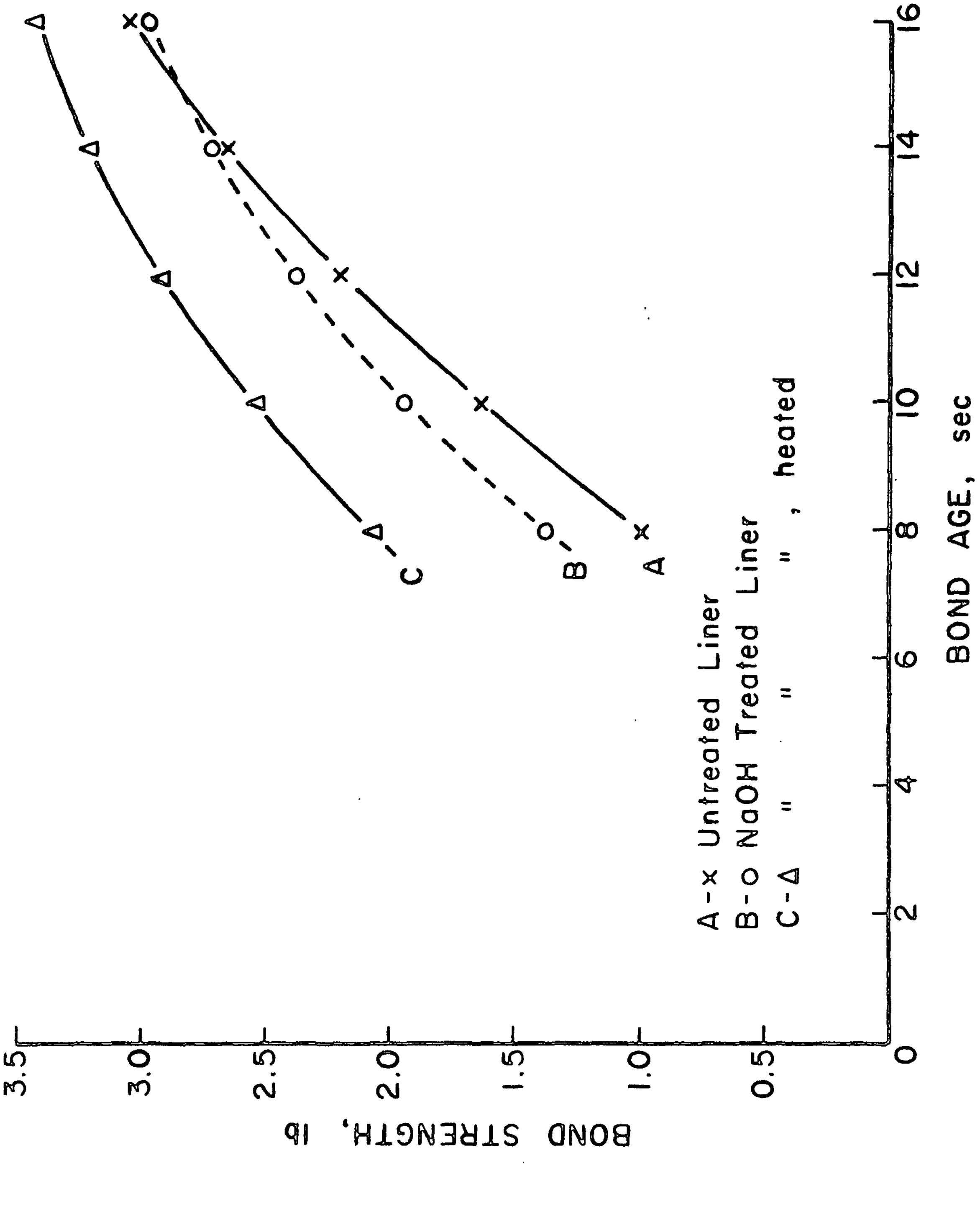


Figure A37. Effects of Liner Treatment and Liner Heating on Bond Rate

Summary

At present, the bond formation system seems to be limited by the transfer of adhesive onto and into the board components. Significant future gains in bond rate will be made on the basis of a better understanding of the mass transfer phenomena involved in the formation and setting of the adhesive bonds.

The bond rate gains from increased solids have reached a limit because of the constraint of incipient dilatency in the starch slurry. We have balanced the high molecular weight desirable for bond strength against the reduction in molecular weight needed to attain good, workable viscosity. At the same time we have obtained a thoroughly cooked starch to give good adhesive stability. No real improvements were noted with the attempts to change the molecular size and shape distribution of the starch adhesive. While some gains may have been made from graft modification, the results are not clear and gains appear limited.

The positive effect of heating the liner on the bond rate implies that the process is limited by transfer phenomena. The effect of treatment of the liner with dilute solutions also implies a transfer limit. The effect is not chemical. Distilled water is essentially equivalent to dilute sodium hydroxide. It is not a matter of surface sizing. The hydroxide-treated liner has lost its surface sizing; the water-treated liner has not, yet the bonds are about alike. The one difference observed in the treated liner is a very slight disruption of the surface fibers, visible under the microscope at low magnification. The effect of liner treatment on the bond strength vs bond age curve appears to raise the curve somewhat preferentially at the shorter times and thus to reduce the induction period. The effect of heating the liner is to raise the curve more or less uniformly (Fig. A37).

In the final analysis, bond development appears to be by drying of the adhesive, that is, by mass transfer of water from the bonding adhesive. This is preceded by an induction period during which full contact is made and the transport gradients are established. The results of our empirical studies with the simulator will form the basis for a more detailed study of these transport processes. Further work will be aimed at achieving further improvements in bonding rate from increased understanding of these phenomena.

For the present, simulator experiments have revealed four practical mechanisms for speeding the transport processes, and hence production speeds. These include:

1. The use of the highest possible starch solids levels in the adhesive. This reduces the total amount of water to be transported and hence the time for that transport to occur.
2. Lower adhesive application rates to reduce the amount of water to be transported into the component. There is, of course, a limit below which bond strength is lost because of an inadequate adhesive supply. Within this constraint bond rate is maximized by minimizing application rate.
3. Higher combining pressures (belt loading) contribute to bonding development rate by supplying an external gradient to drive the transport processes. Combining pressures well above those normally used is helpful but maximum pressure is limited first by equipment structural design and second by board crushing.
4. Raising the liner temperature is a very powerful mechanism for shortening the induction time, and perhaps enhancing the rate processes, both of which speed bonding. Typically a 75°F rise in liner temperature will double the bonding rate. Thus by returning a small amount of energy - about 10% - to the process via liner perheating a substantial increase in DF bond development rate can be achieved.

These four practical steps, less adhesive, higher solids, more double backer pressure, and liner preheating, constitute the essential changes suggested by simulator results. Pilot trials designed to achieve these operating conditions (insofar as possible within the limitations of the simply converted pilot system), have resulted in the production of marketable board at commercial production speeds. The commercial evaluation equipment is designed to provide more nearly optimum operating conditions which should lead to even better performance.

PART B - COLD CORRUGATING EQUIPMENT

INTRODUCTION

The Institute of Paper Chemistry has entered into a contract with the U. S. Department of Energy for the commercial evaluation of the cold corrugating process. In support of this contract, IPC has entered into a subcontract with Union Camp Corporation to provide its box plant in Savannah, Georgia, as the host site for the cold corrugator. The cold corrugating equipment will be installed in an existing corrugator line. New equipment, necessary for the commercial evaluation of cold corrugating, includes a single facer, glue machine, double backer, slurry make-up system, adhesive preparation and distribution system, and a data acquisition system. The purpose of Part B of this report is to describe the design of these items of equipment, to indicate the current operational status of each, and to present general information about the commercial evaluation portion of the project.

In the context of commercial evaluation, the cold corrugating system may be regarded as being made up of the process, the corrugator, an adhesive make-up and distribution system, the data acquisition system, and a data base. On the corrugator, the single facer, glue machine, and double backer require designs modified to accomodate the cold process. An adhesive system different from that presently used is also required. Collectively, these four units constitute the so-called risk machinery since they involve new design features. All remaining corrugator units are unaffected by cold corrugating and constitute the non-risk machinery, so named because there is no new risk in their design or operation. The non-risk equipment has been supplied by the host company. While intended primarily for acquiring data during the experimental portions of the commercial evaluation program, the data acquisition system will also provide information from which to identify the instrumentation required for second generation commercial machines. A commercial evaluation data base, useful for assessment of the process and future application of it, will be generated during the commercial evaluation phase.

The new equipment named on the previous page is being installed in an existing corrugator to provide single-wall cold corrugating capability. Additionally, there are C-flute and B-flute single facers in the line to give a parallel hot double-wall capability for at least the early phases of the project. The single facers are equipped with Langston Model J.P. roll stands, some with Butler splicers. The dry end equipment consists of a Langston rotary shear and triplex, a Koppers direct drive knife, and Martin automatic stackers. All of the cold corrugating equipment is designed to operate at 650 fpm and to accommodate 96" wide paper.

Each piece of cold corrugating equipment is being installed and checked out in such a way as to minimize disruptions of normal production. At the present time all equipment except the double backer and its associated instrumentation has been installed. Except for time needed to conduct tests on the cold equipment the corrugator will be available for normal hot single or double-wall production until the double backer is installed at which time only cold corrugating production will be possible.

All of the equipment is based on the best available hot corrugating equipment redesigned in the minimum way for cold corrugating. This design philosophy offers several advantages: It has helped to minimize design expenses for this project; it will simplify conversion back to hot corrugating machinery if necessary; and, it will help establish the requirements for retrofitting of hot machinery to cold corrugating equipment.

New equipment included in the system and the corresponding supplier is indicated below:

System Component	Supplier
Adhesive System Slurry makeup system Thermo-chemical conversion unit Adhesive distribution system	SAECO
Single Facer	Koppers
Glue Machine	Koppers
Double Backer	S & S
Data Acquisition System	Analog Devices

In the following sections the salient design features of each of these units and the results of operating experience to date are described.

SINGLE FACER

A Koppers 98" C-flute fingerless single facer is being used for the cold corrugating commercial evaluation. Figure B1 shows some of the features of this machine.

General Design

The machine is basically a standard Koppers hot fingerless single facer with modifications as required for cold corrugating. These standard or slightly modified features are included:

1. Nominal 12" diameter C-flute corrugating rolls, laser hardened and chrome plated.
2. Nominal 13 3/16" diameter case hardened pressure roll with a brass scraper blade.
3. Direct drive to bottom corrugating roll with an air clutch drive for the pressure roll.

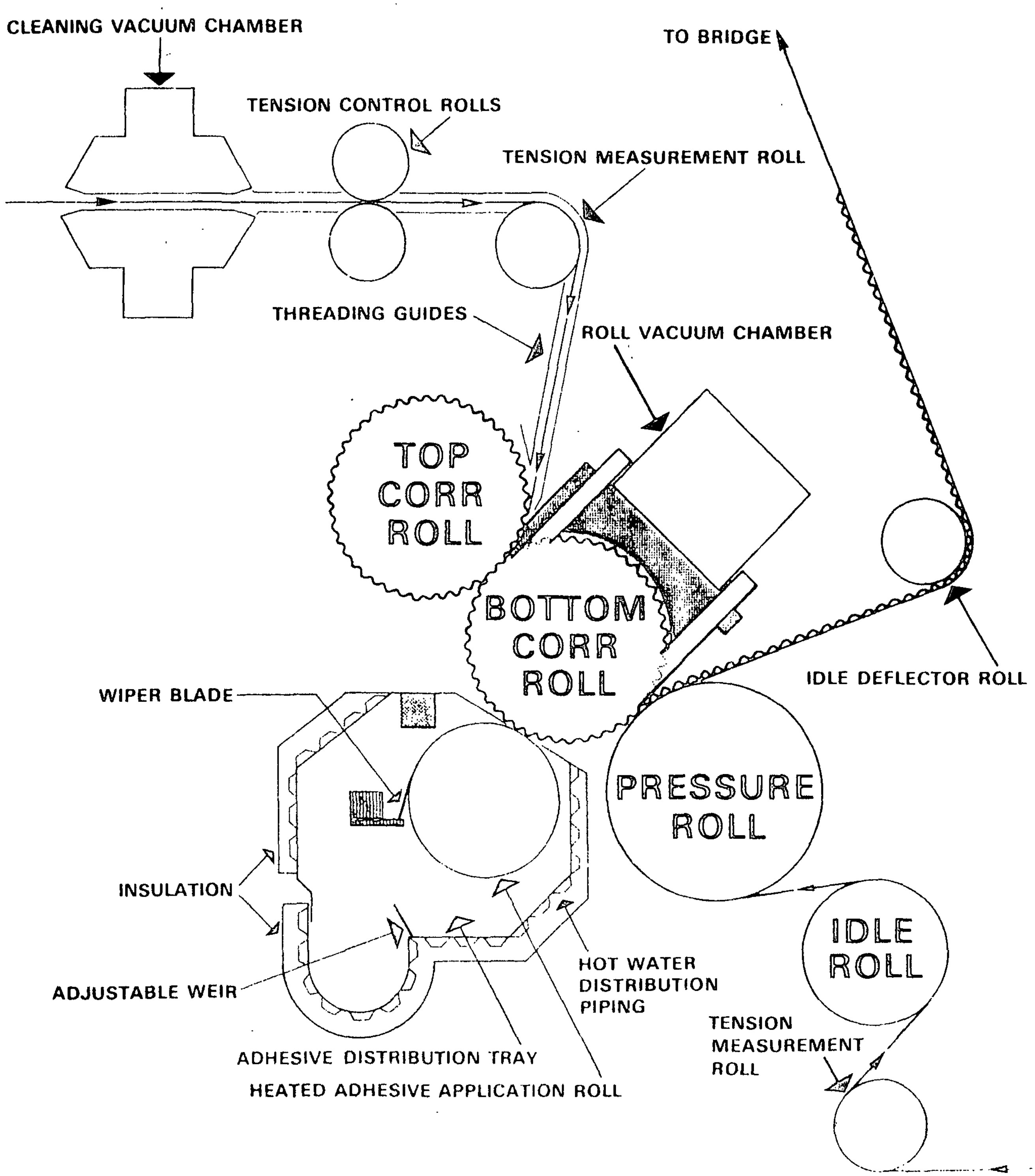


Figure B1. Cold Corrugating Single Facer

4. Roll stack designed for pneumatic loading of 225 lbs per inch for the corrugating roll and 150 lbs per inch for the pressure roll which will operate against stops. These design load values are slightly higher than those used for hot corrugating.

5. All normal steam connections have been retained, although not used.

6. An air pressure loaded medium treatment applicator utilizing cast bars is incorporated.

Fingerless Design

A fingerless single facer design was selected for the following reasons:

1. It is the current state-of-the-art and the design of the future and therefore should be the design used for the cold corrugating commercial evaluation.

2. The elimination of fingers permits consideration of several new application concepts, a feature most important to cold corrugating. The design is also mechanically clean to facilitate clean-up.

3. Fingerless designs have been shown to produce board with improved structural properties and there is evidence that they are more tolerant to paper variations.

4. Fingerless designs may show even greater advantages for cold forming.

The Koppers fingerless design utilizes slots 0.080" wide and spaced approximately 2" apart along the lower corrugating roll. A vacuum is applied to the slots by means of a chamber wrapped around the portion of the roll not covered by paper. A vacuum of approximately 25" H_2O, applied between the surface of the roll and the medium, assures intimate contact between the medium and the corrugating roll. The vacuum is generated by a 40-HP blower that produces a flowrate of 700 CFM.

A larger blower is used on this cold machine to compensate for the higher density of the cold air. Preliminary evidence suggests the blower is oversized. Although there are provisions for closing unused slots when narrow paper is used, this has been found to be unnecessary.

Medium Tension Control System

It is very desirable to feed the medium to the corrugator at a constant and controllable tension and to minimize dragging of the medium over the top corrugating roll. To accomplish this, an idler roll guides the medium straight into the corrugating nip. This roll also measures tension in the medium at a point immediately ahead of the corrugating nip. A motor-driven nip drive uses the measured tension value to achieve fine tension control, nominally over the range from 0.5 to 4.0 lbs per lineal inch. A dancer roll between the roll stand and the web feeder system provides a signal to adjust the roll stand brake. This system provides coarse tension control and minimizes tension spikes.

As an additional function, the nip drive is used during threadup to pull the medium into the machine. In this mode the nip closes softly to provide just enough pull to accomplish threadup but not enough to break the medium when the corrugating rolls take over the pulling function. The complete tension control/threadup system is shown schematically in Figure B2.

Liner Tension System

Another machine-mounted idler roll measures liner tension for data acquisition purposes only. Liner tension is controlled by a feedback signal from a dancer roll to the brake on the liner roll stand. Control over the range from from 0.25 lbs per lineal inch to the capacity of the roll stand will be possible. The dancer roll will also minimize tension spikes. This system is shown schematically in Figure B3.

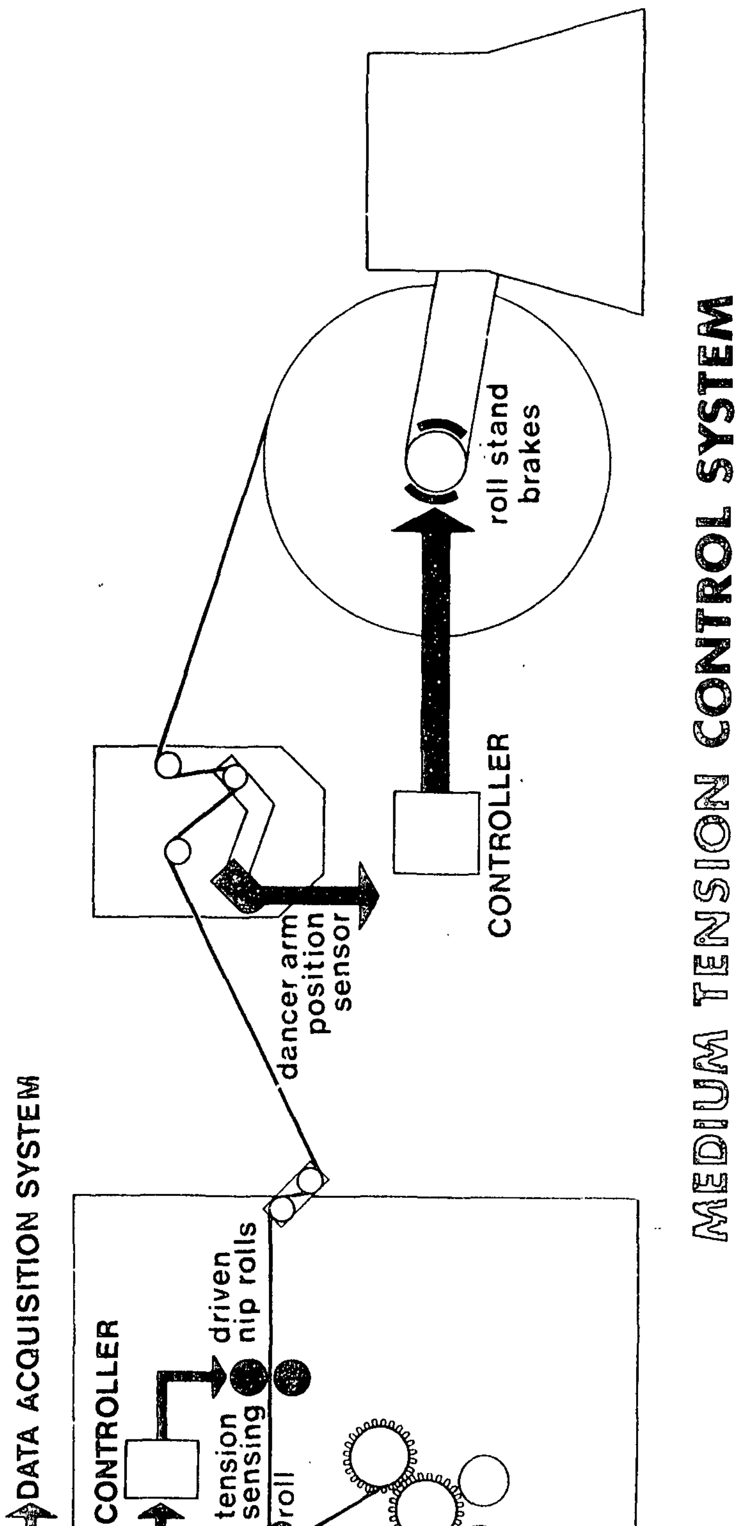
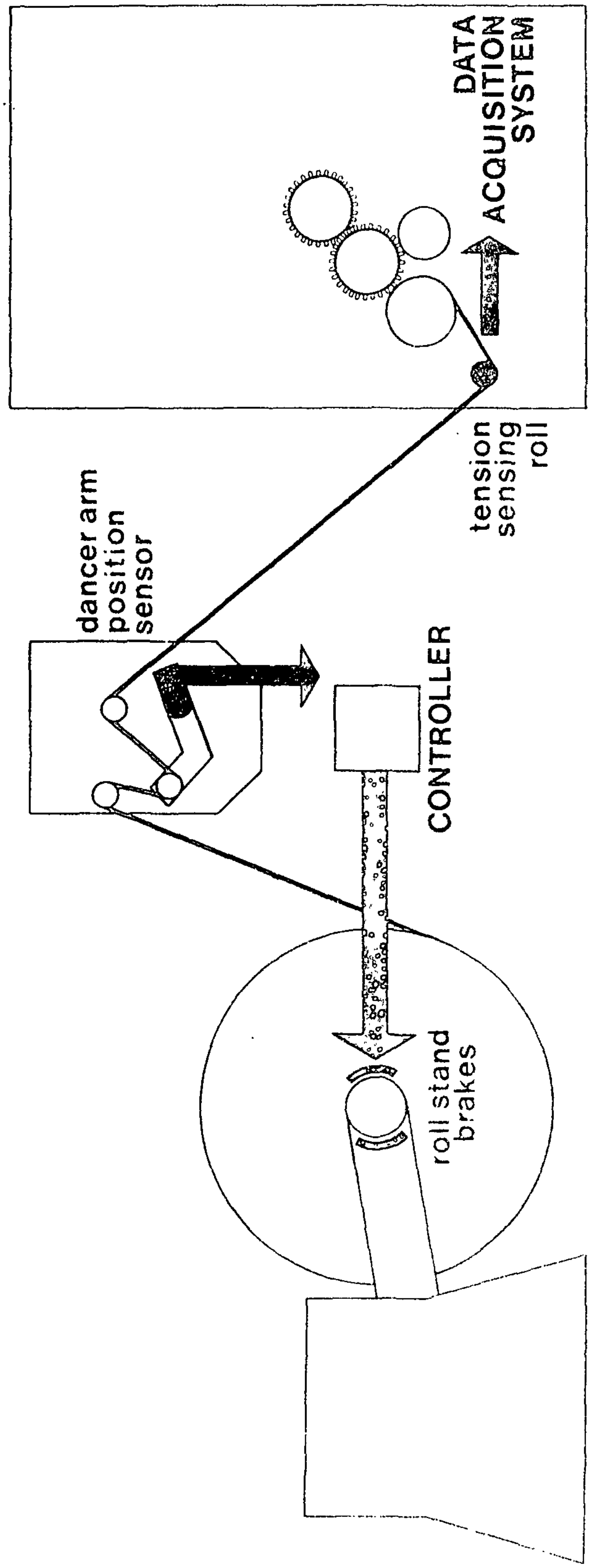

DATA ACQUISITION SYSTEM
CONTROLLER
tension sensing roll
driven nip rolls
dancer arm position sensor
CONTROLLER
roll stand brakes
MEDIUM TENSION CONTROL SYSTEM

Figure B2.



LINER TENSION CONTROL SYSTEM

Figure B3.

Web Cleaner

Loose debris on the medium roll surface may be dislodged by the medium treatment applicator and other equipment. To minimize the potential for this debris to collect on the corrugating rolls, a web cleaning system is included on the single facer. This unit consists of a vacuum hood mounted on the top of the single facer before the tension control nip drive. A second, smaller blower supplies vacuum for the web cleaner.

Adhesive System

The adhesive application system is designed to occupy the position of the conventional glue pan and applicator system without requiring other machine modifications. For cold corrugating, it is necessary to maintain the temperature of the adhesive at 190°F to 200°F at all times. To do this, the adhesive pan is water jacketed and heated with a constant flow of hot water supplied from the adhesive supply line water jacket. The water flows through the various temperature control units and then to the adhesive return line water jacket. All areas wetted by the adhesive are heated. All external surfaces that are heated are insulated for operator protection and energy conservation.

The entire application system is shrouded except for the minimal opening needed to apply the adhesive. The opening is automatically closed any time the applicator roll is not in contact with the web. The shrouding serves two purposes; first, it reduces heat and moisture losses, and second, it prevents vapor from the adhesive system from condensing on the cold corrugating rolls.

Care is taken in the design of the single facer adhesive system to prevent stagnation of the adhesive and to provide a steady flow of adhesive from the supply line, through the applicator system, and back to the adhesive tank via the return line.

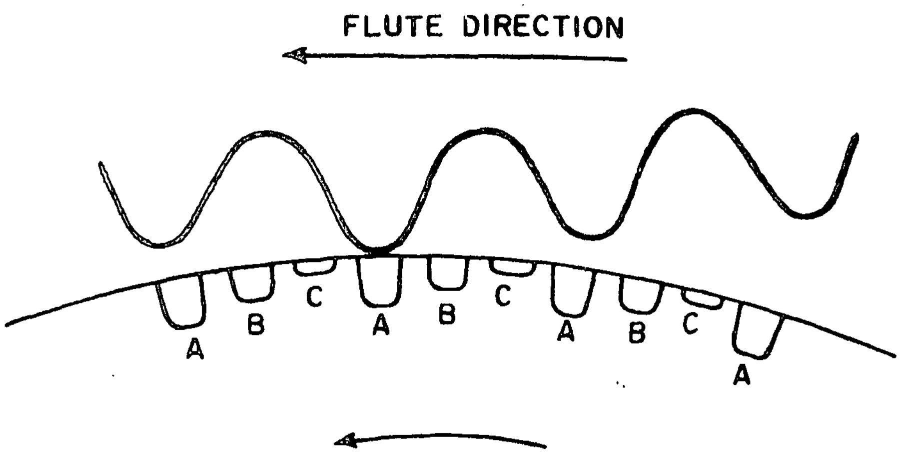
Adhesive for the single facer station flows from the supply line, through a mass flow meter, and to the inlet of the glue pan. Unused adhesive overflows a fixed weir in the pan and returns by gravity to a sump. A level sensor in the sump is used to set return pump speed at the proper value. Returned adhesive is pumped through a second mass flow meter and back to the storage tank via the adhesive return line. Data from these flow meters along with paper width, running speed, and adhesive solids content are used to calculate adhesive application rate in pounds of starch per thousand square feet of board.

Adhesive application at the single facer is accomplished by a "banded" gravure roll operating with a doctor blade. The doctor blade holder is designed so the blade can be used either as a reverse angle or trailing blade. The blade doctors all adhesive from the roll except that held in the gravure cells. Both the gravure roll and the doctor blade holder are heated by circulating hot water to aid in adhesive temperature control.

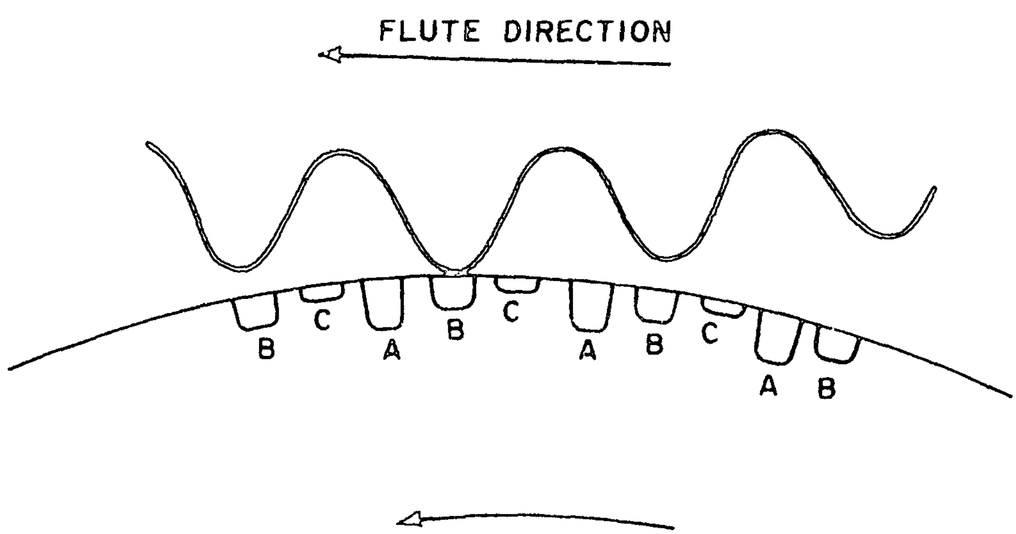
Figure B4 illustrates the "bands" on the gravure roll. These "bands" run parallel to the roll axis and are repeated at circumferential intervals of 0.306" which corresponds to the spacing between flute tips. Each "band" has three patterns which differ only in depth. The depths have been selected to yield three adhesive application rates in the range from .75-1.25 lbs/MSF. Since the glue roll is driven by a set of 1 : 1 helical gears, sliding one gear axially indexes the glue roll relative to the lower corrugating roll. A ratchet wrench on the operator's side is used to set this indexing system to give the desired pattern. The indexing arrangement is shown schematically in Figure B5.

Because the gravure roll is wiped clean, transfer of adhesive from the glue roll to the corrugating roll in the regions outside of narrow paper is unlikely. As a consequence this system is designed to run with full wetted

VARIABLE ADHESIVE APPLICATION RATE



INDEXED FOR HIGH APPLICATION RATE



INDEXED FOR MEDIUM APPLICATION RATE

Figure B4. Adhesive Application Roll

SINGLE FACER APPLICATION RATE ADJUSTMENT

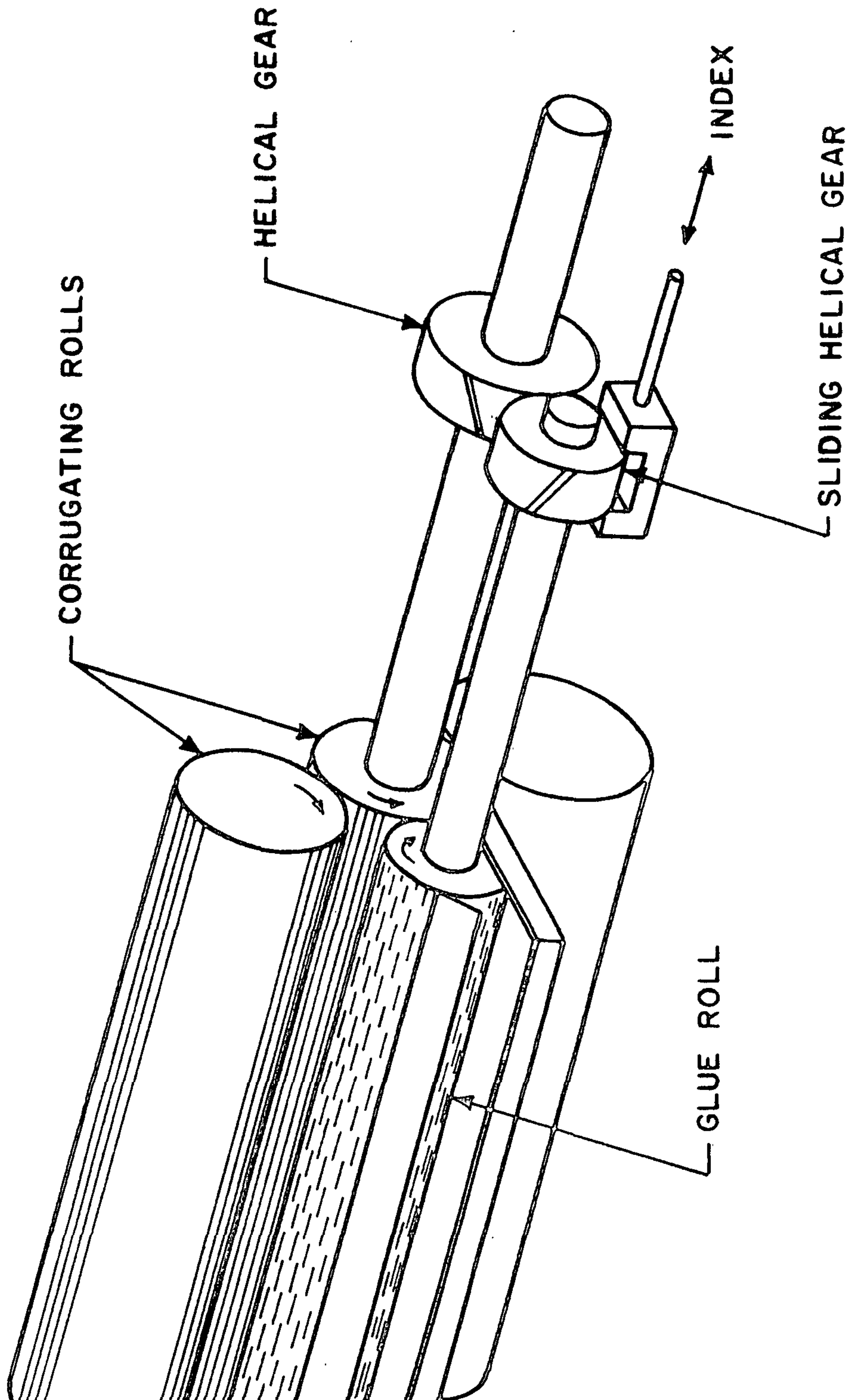


Figure B5.

widths at all times, i.e., it does not have adjustable side dams. This feature gives full width bonding on the medium and avoids dam adjustments between orders.

The adhesive pan and the entire single facer adhesive system have been designed with minimum volume and surface area to reduce heat and vapor losses, and to minimize wasted adhesive. To facilitate cleanup stainless steel has been used for most stationary wetted parts and the system is equipped with a hot water cleanup feature. This system has worked very well with cleanup taking only a few minutes, even after prolonged running.

Instrumentation

All of the instrumentation typically found on a single facer has been retained and the additional conventional instrumentation required by the cold corrugating system and useful to an operator has been added. The data acquisition system, by operating in a parallel fashion, will monitor all of these variables plus many others. The intent is to provide a complete data acquisition system for experimental pruposes but to also provide independent parallel instrumentation to allow routine operation of the corrugator without the data acquisition package.

The variables to be monitored at the single facer by the data acquisition package (DAP) are as follows:

1. Liner and medium speed.
2. Liner and medium temperature.
3. Liner and medium moisture content.
4. Liner and medium tension.
5. Medium width.
6. Medium treatment applicator (on/off).
7. Adhesive application rate.
8. Corrugating and pressure roll loads.
9. Adhesive and water jacket temperature.
10. High-lows (flute height differentials).
11. Bridge stock.

Operation

At this writing the single facer has been operated at speeds up to 350 fpm for short periods of time. Although prolonged running at high speeds is needed for a complete checkout, preliminary results are encouraging. The application system is giving approximately the designed values for application rate and the pin adhesion values are good. The threadup feature and the tension control feature on the medium are both excellent. Capture of the medium by the vacuum system is generally good and it appears that a smaller blower would suffice. Cleanup of the system with the special washing system has been very good, far exceeding expectations based on pilot trials.

GLUE MACHINE

A Koppers triple deck glue machine is now installed. The bottom unit is designed for the cold corrugating process while the top two units are of conventional design. These will allow Union Camp to maintain hot double-wall production through much of the early cold system evaluation and hence minimize lost production.

General Design

Ultimately, the glue unit will be driven by a timing belt from the lower tail pulley on the new double backer. In the interim, while the old double backer is being used, the drive is obtained from the upper tail pulley via a jack shaft arrangement.

Since the glue machine and single facer use the same adhesive and the same application rates are desired, most of the design concepts for the glue machine applicator system are the same as those used at the single facer. In particular, the adhesive metering and transfer system consists of a similar heated, specially engraved gravure roll and doctor blade. The gravure patterns for the two rolls are identical.

The glue roll is driven by a harmonic drive acting as a differential. One input is obtained directly from the double backer; the second from a control motor. An optical flute position sensor determines the position of the average flute relative to the selected roll pattern. This signal is used to drive the control motor to register the selected gravure pattern with the flute tips. A change in adhesive application rate is obtained by selecting a new band pattern through the electronic system. This general arrangement is shown schematically in Figure B6.

All stationary surfaces wetted by the adhesive are temperature controlled by jackets heated with hot water supplied from and returned to the adhesive supply system. Hot water also flows through the blade assembly and glue roll to assist in temperature maintenance. The entire system is shrouded except for a small opening to allow application to the single face web. The opening closes automatically when the single face web is not moving.

The adhesive supply and return system used at the glue machine is identical to that used at the single facer. The entire system is designed to assure steady adhesive flow with no stagnant areas.

A conventional air actuated rider roll with positive adjustable stops controls contact between the single face web and the glue roll.

Instrumentation

The general concept for instrumentation of the single facer applies to the glue machine and double backer as well. Specific variables to be monitored at the glue machine by the DAP are as follows:

GLUE MACHINE APPLICATION RATE ADJUSTMENT

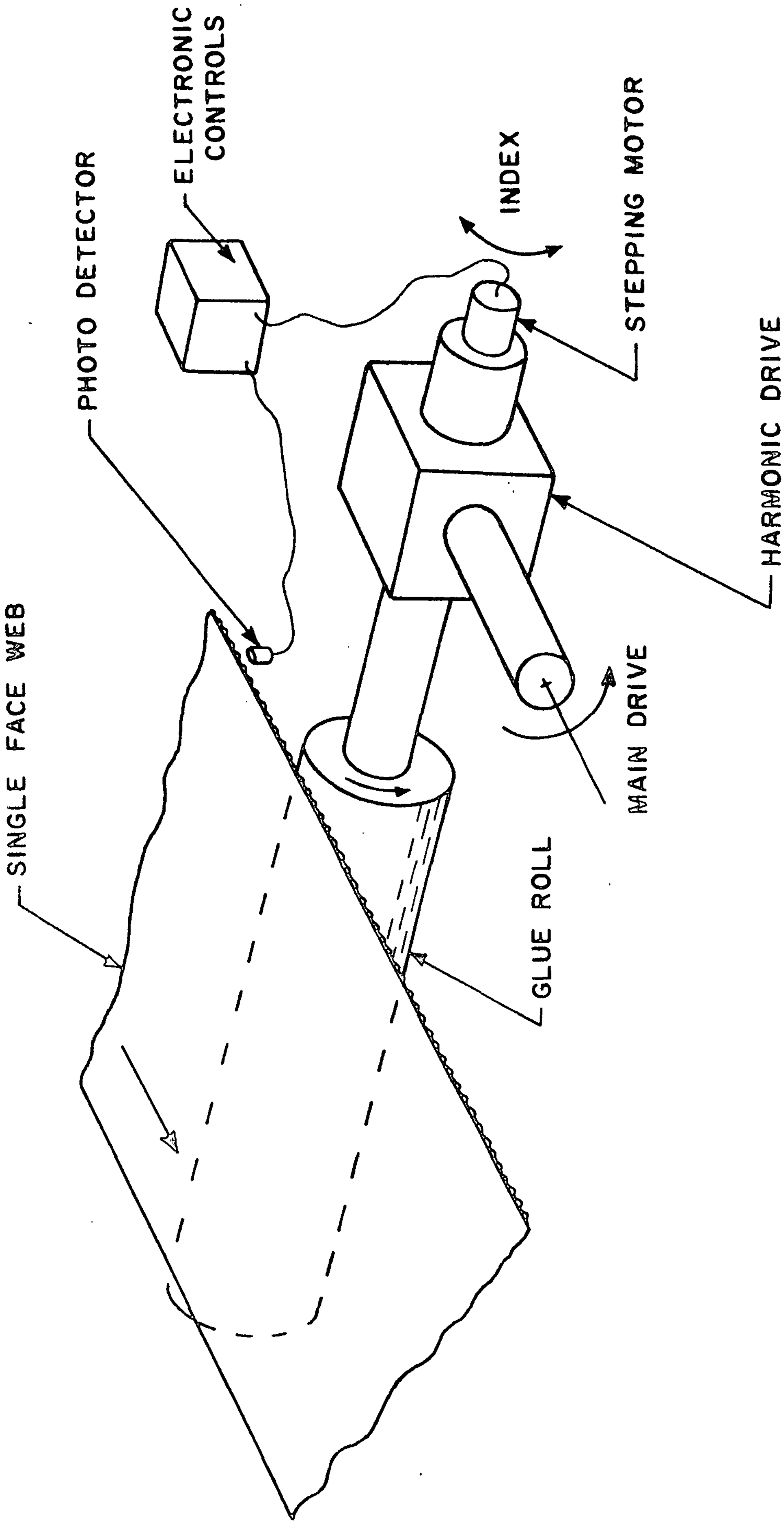


Figure B6.

1. Single face web and double face liner temperature.
2. Single face web and double face liner moisture content.
3. Single face web and double face liner tension.
4. Adhesive application rate.
5. Adhesive temperature.
6. Adhesive water jacket temperature
7. Rider roll gap.

Operation

The glue machine is in the early stages of check out. Severe short term variations in double backer drive speed have necessitated redesign of the register control system to permit proper tracking. One or two more trials should serve to determine the ability of the servosystem to maintain register and hence application rate control.

DOUBLE BACKER

An S & S Model 763 (HE) 97" double backer, modified as required for cold corrugating, has been ordered. This machine is currently assembled for testing in the S & S shop. Delivery at Savannah is expected shortly. Installation will occur when the single facer and glue machine are adequately checked out.

General Design

The machine is 64 feet long with full length Dacron belts both over and under the board. The side frames, head pulleys, head pulley stand, tension stand, tail pulleys, and tail pulley stand are all standard or slightly modified components. The side frames, where the hot plates would normally be mounted, are slightly modified to accommodate roller brackets. These brackets will positively constrain support rollers under the lower belt and horizontally constrain weight rollers over the upper belt. These brackets are identical with those normally used in the pulling section.

It is desirable to bring the single face web and double face liner into intimate contact as quickly as possible and under as much pressure as possible. For this reason, the entry section of the double backer was given special attention. A 4" weight roll is located immediately after the tail pulley above the top belt and a corresponding 4" support roll is located under the bottom belt. These serve to close the throat quickly to minimize open time while still allowing for eventual multi-wall production.

For the remainder of the machine each roll bracket is designed to hold 10 rolls on the top and 10 on the bottom, all on 3 1/4" centers. If 10 top rolls with the normal diameter of 2 7/16" are used, the resultant loading is about 0.4 psi. To provide extra loading and load control in the first two roll sections (6 feet), the 2 7/16" diameter rolls are replaced with 3 1/8" diameter rolls and the roll brackets are fitted with double acting pneumatic actuators. This combination allows load control over the range from 0 to 1.0 psi. To provide adequate support 3 1/8" rolls are also used under the bottom belt. To provide uniform belt height, these oversized support rolls are used over the full length of the machine (Fig. B7).

The next two sections (6-12 ft.) of the double backer have a full complement of 2 7/16" weight rolls to give a loading value of up to 0.4 psi. The remainder of the double backer has 2 7/16" rolls in a normal spacing pattern but can be fitted with the extra rolls if necessary. In total, there are 96 weight rolls and 124 support rolls.

It is estimated that a 50 HP drive will be adequate for the two-belt system, even for multi-wall product. The host plant specifications require, however, that the drive be sized to accommodate hot triple-wall operation, should

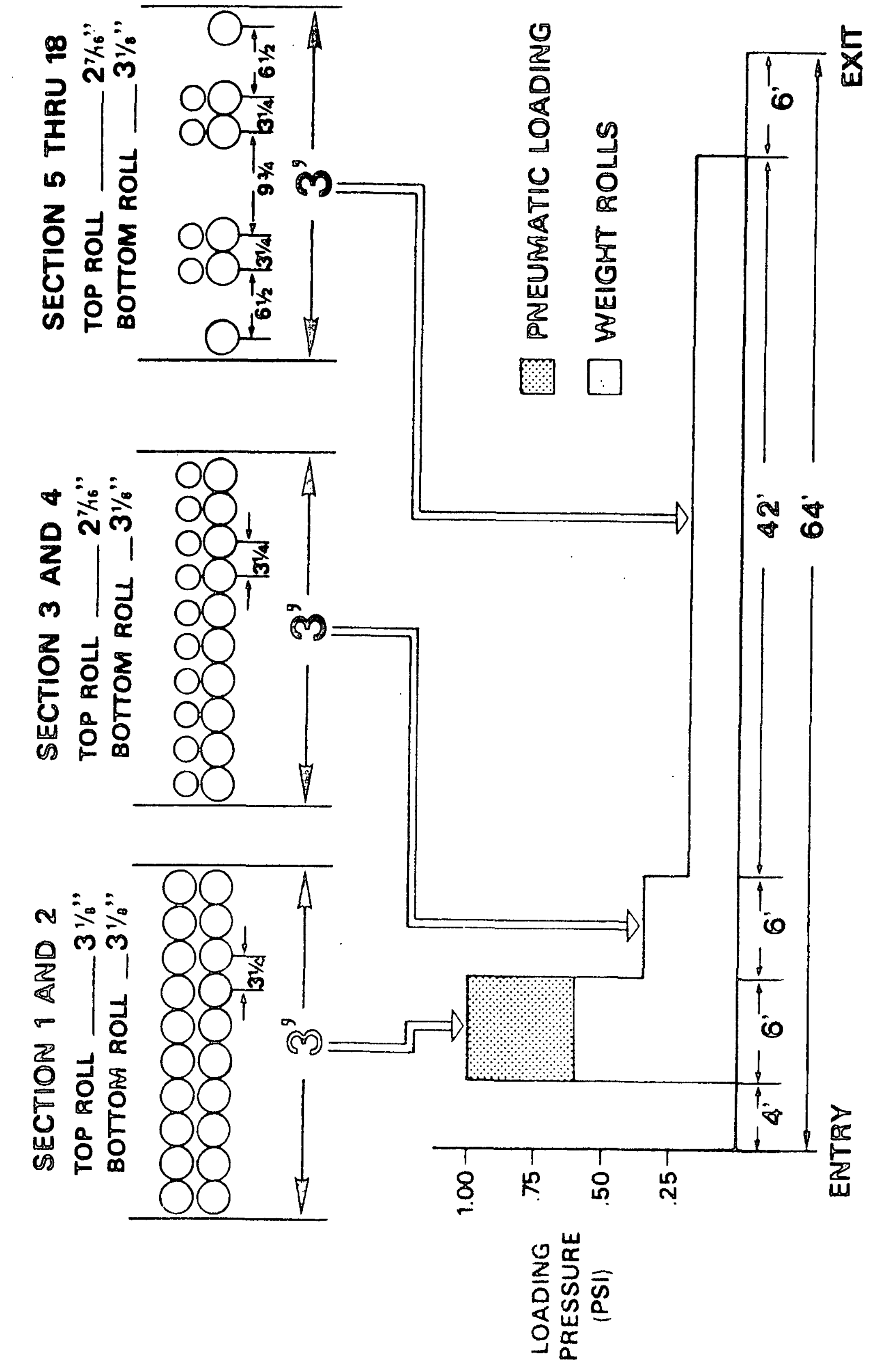


Figure B7. Cold Corrugating Double Backer that be necessary. To meet this requirement a 150 HP drive has been supplied. The drive motor is coupled directly to the lower belt and to the top belt through a Reeves variable speed drive. This permits differential speed adjustment to minimize shear on the freshly combined board. Precision speed sensors facilitate adjustment of the Reeves drive. Manual adjustment of the drive is provided on the assumption the ratio will not need frequent adjustment.

The top belt has a standard pneumatic take-up device for belt tension while the bottom belt has a manual take-up. Both belts are full width with automatic belt tracking.

To complement the double backer, closed loop tension control has been supplied for both the single face web and the double face liner. A disc brake on the roll stand, coupled to the tension sensor in the liner splicer, controls liner tension. Single face web tension is controlled by means of an idler roll tension sensor controlling a rotating lagged drum with a disc brake, as shown in Figure B8. Both web tensions are controllable over the range from 0.25 to 4.0 psi.

The new double backer is shorter than the old one. This resulting gap will be closed with a low friction sheet metal table. Special combined board instrumentation will be mounted on this table.

Instrumentation

Special instrumentation is to be added to the double backer for monitoring board characteristics. The variables to be monitored by the DAP include the board speed, and moisture and temperature on the top and bottom of the board. The latter sensors will be scanned to provide moisture and temperature profiles.

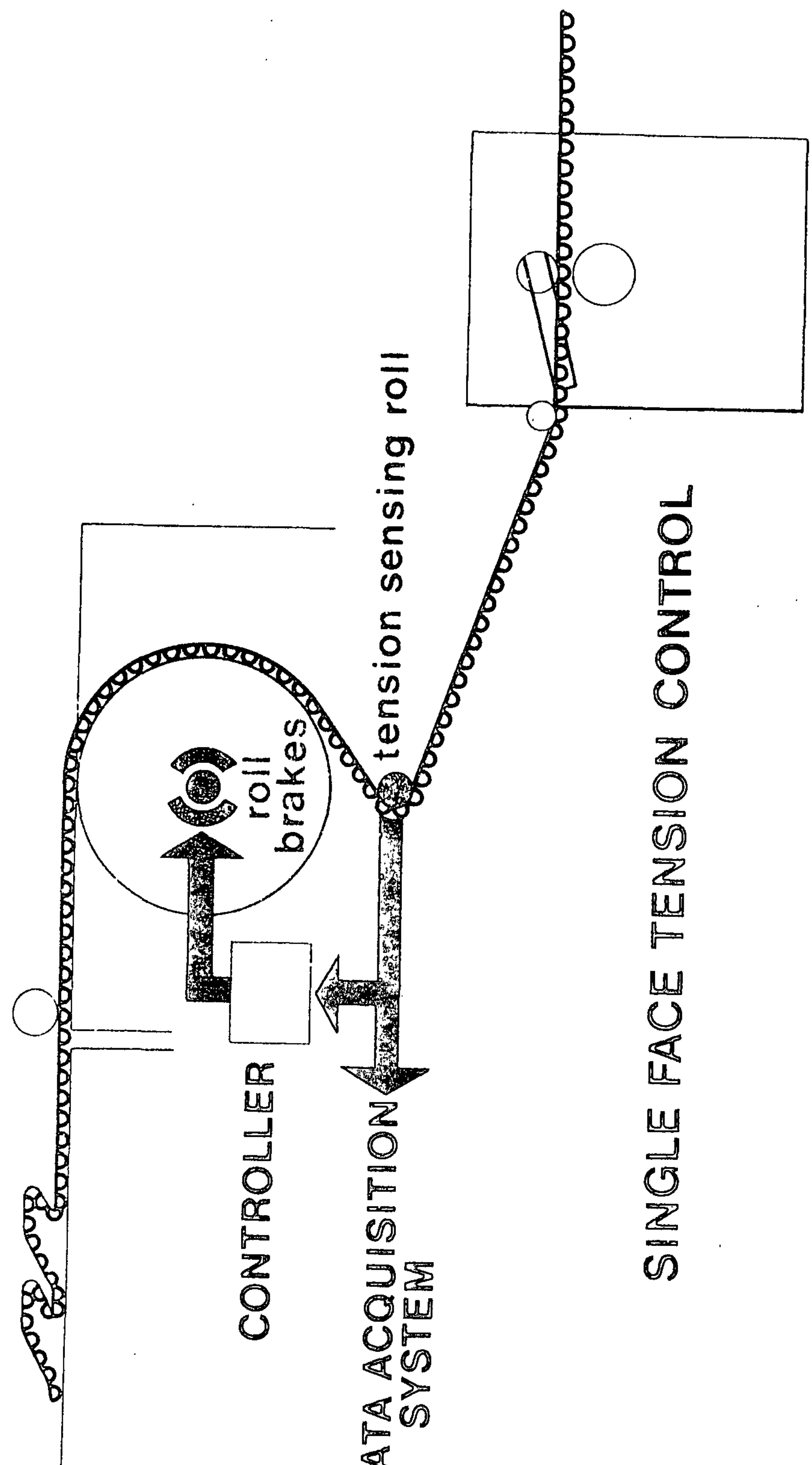

tension sensing roll
roll
brakes
CONTROLLER
DATA ACQUISITION
SYSTEM
SINGLE FACE TENSION CONTROL

Figure B8.

ADHESIVE SYSTEM

A new slurry and adhesive preparation and distribution system is installed as required by the cold process. This will also allow simultaneous running of the cold corrugator with the present hot corrugators at the plant.

General Design

A slurry make-down tank is located near the present starch storage area and a slurry storage tank is located near the thermal conversion unit which, in turn, is located on the drive side of the glue machine. Since the slurry is prepared from bagged starch a vented hood is provided to minimize dust in the area.

Slurry from the make-down tank is pumped to the stroage tank. Both the storage tank and the thermo-chemical conversion (cooking) system are located near the glue machine. In the cooking system, ammonium persulfate is metered directly into the slurry stream through a metering pump with a flowrate controller. The slurry then passes through a Hydroheater cooking unit and into a coil to provide a holding time of about four minutes under proper cooking conditions. Caustic is metered into the cooker exit stream to achieve proper adhesive pH. After caustic addition, the adhesive passes through a flash tank and into a heated adhesive storage tank. The adhesive is delivered to the use stations via a hot water jacketed distribution line. Excess adhesive is returned to the storage tank via another jacketed line. Hot water for temperature control at each of the use stations is drawn from and returned to the jackets of the adhesive circulation line.

The hot water system for supplying the jacketed pipe and adhesive storage tank jacket is a closed loop system with a hot water storage tank. Temperature of the system is maintained by a second Hydroheater.

Slurry System

This system utilizes bag starch and has a starch dust collection system which feeds the dust directly into the slurry tank. Figure B9 shows a schematic of the slurry make-up system.

The slurry make-up operation is manual and requires an operator to meter a predetermined quantity of water into the tank and to add a predetermined number of bags of starch through the bag dumping system.

The system is designed with interlocks so the dry starch conveyor will not convey starch into the slurry tank unless there is a minimum level of water in the tank, as sensed by the tank level transmitter, and the agitator and the pump are both operating.

The dry starch entrance to the slurry tank is fitted with a wetting device which eliminates the dusting of starch as it drops into the tank. A trough-like deflector, located below the wetting device, deflects the slurry against the tank wall, thereby providing additional mixing for dispersing the starch with miminum air entrainment.

The make-down water is metered into the tank with a Neptune volumetric meter which is manually set for the desired batch size.

The slurry make-down tank automatically transfers to the slurry storage tank on receiving a low level signal from the slurry storage tank level transmitter.

As soon as the slurry make-down tank goes empty, an alarm signal notifies the operator the tank is empty so he can make arrangements to make up another batch.

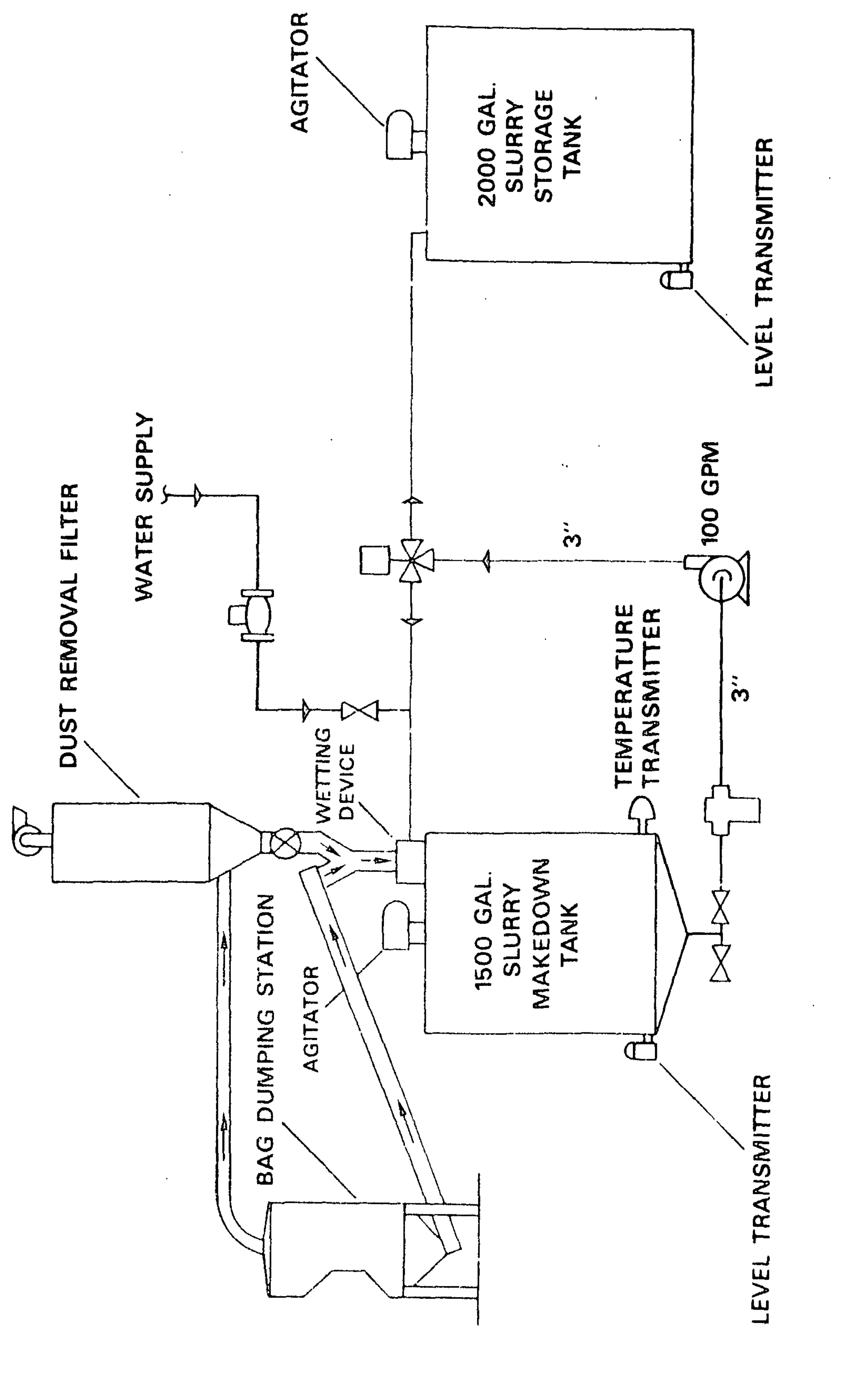


Figure B9. Slurry Make-up System

The slurry storage tank is sized at 2,000 gallons to provide sufficient slurry for at least two production shifts at high production rates. The make-down tank volume is 1,500 gallons so that a batch can be made up and dumped to the storage tank before the storage tank is completely emptied. Both tanks are of 304 stainless steel and continuously agitated. Slurry is transferred from the make-down tank to the storage tank at the rate of 100 gpm by a centrifugal pump. Levels in both tanks are monitored by differential pressure cells.

Thermal Conversion System

The adhesive preparation system is designed to cook the slurry at 10 gpm. The slurry is delivered at this rate to the cooker by a Moyno pump. Prior to entry to the pump, ammonium persulfate is metered into the slurry by an ECO pump and flow controller. The control system insures that AP is added only to slurry entering the cooker and not to slurry being recirculated. The AP flow rate is controlled by an orifice-type flow meter. AP is stored in an agitated 10-gallon tank located at the cooker. A type J, size 600, Hydroheater is used for cooking the slurry. Cooking temperature is automatically maintained at any preselected value in the range from 270°F to 330°F by supplying a steam flow in direct proportion to slurry flow.

A Foxboro control valve automatically maintains the cooker back pressure at any preselected level between 10 and 100 psig. The slurry is passed through a coil at the high pressure and temperature to provide a holding time of four minutes to insure complete conversion of the starch. The coil consists of 4" stainless steel pipe wound in a helical coil approximately 4'6" in diameter by 5' high.

After exiting from the holding coil, NaOH is metered into the adhesive to attain a pH of 6-10. A Foxboro pH controller and pump are used to control the NaOH addition at the desired set point. There are also provisions for controlling the caustic addition rate as a direct ratio to the AP flowrate or at a preset and fixed rate. The sodium hydroxide is stored in a 10-gallon tank located near the cooker. The adhesive flows through a static mixer to assure proper mixing of the caustic and then to a flash tank. Adhesive flows by gravity from the flash tank to a 500-gallon storage tank. This tank is jacketed, insulated, and agitated. Hot water flowing in the jacket maintains the storage tank at approximately 200°F. Figure B10 shows a schematic of the thermal conversion system.

Adhesive Distribtuion System

The adhesive in the storage tank is circulated through a loop to the glue machine and single facer. The recirculating loops are water jacketed with hot water flowing in the jackets. The line to the glue machine is fabricated from 2" 304 stainless steel pipe jacketed with 4" carbon steel pipe; beyond the glue machine 1 1/4" stainless and 3" carbon pipe are used. The lines are covered with 1" of insulation. The pipe is assembled in flanged sections to allow for easy disassembly. Flushing connections, drains, air vents, and expansion joints are provided as necessary.

Adhesive is pumped at a rate adjustable up to 40 gpm through the recirculating loop. Valved tees are provided for take off at the use stations. Excess adhesive from the use stations is returned to the recirculating loop and flows back to the storage tank. A dual filter unit with 30 mesh screen is located in the return line to remove any foreign material from the adhesive.

A separate water tank holds wash water, heated in the cooker condenser, for purging adhesive lines and cleaning use stations at shutdown. In the event

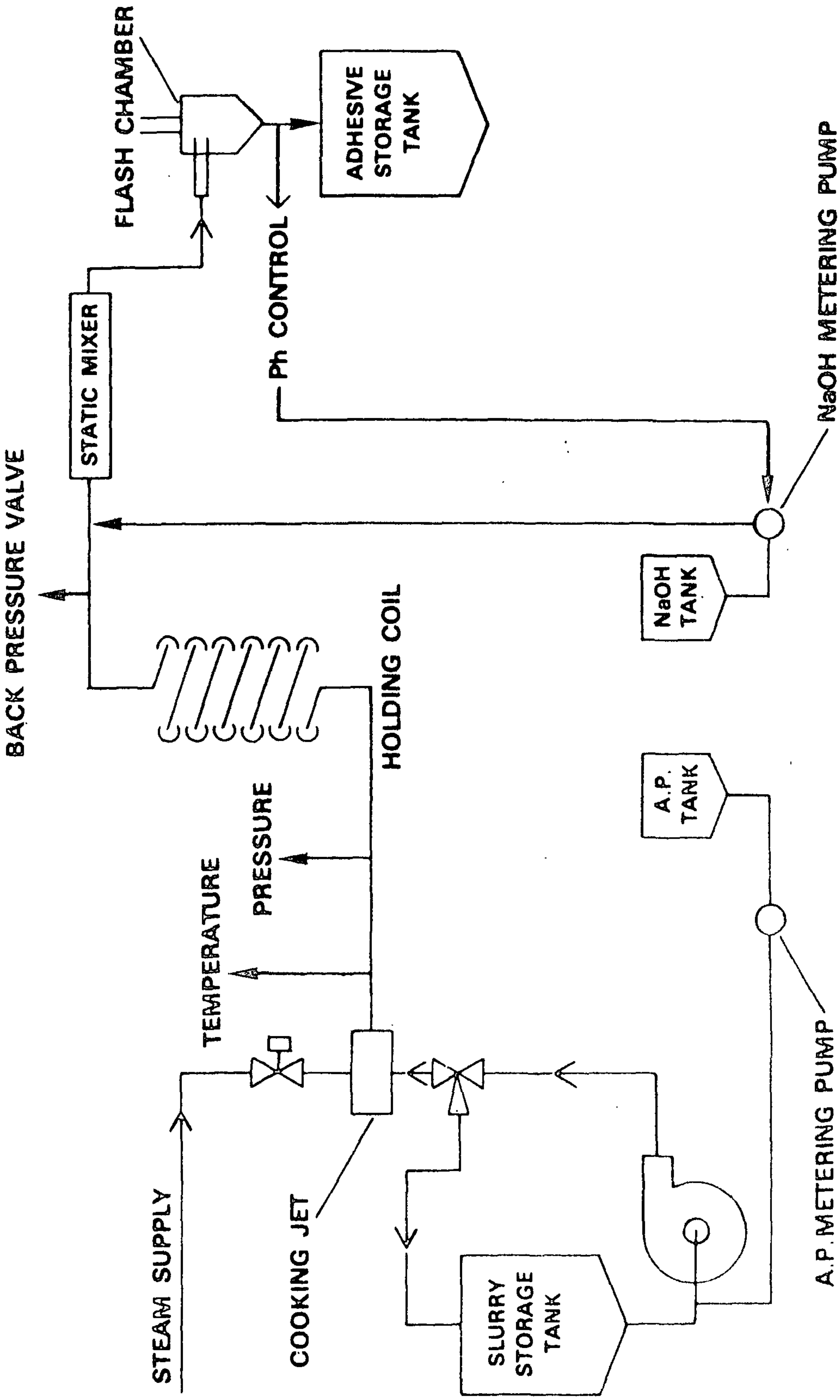


Figure B10. Thermal Conversion System

of a prolonged power outage, an auxiliary generator will provide power for purging and clean-up.

Hot water from the jacket is drawn off at each use station to circulate through the glue pan water jackets, applicator rolls, and blade holders. This water is circulated through the use station and then back to the water jacket. Figure B11 illustrates the adhesive and hot water distribution system.

Hot Water System

A 500-gallon insulated storage tank acts as a surge tank for the hot water system. This is a carbon steel tank which is insulated to minimize heat loss and for operator protection. It is a closed loop system so the hot water is continuously recirculated from the surge tank through a Hydroheater equipped with automatic temperature control to maintain the hot water at the preset temperature.

The total volume of water in the jacketing of the adhesive storage tank, the adhesive piping, and the use stations is about 250 gallons. The hot water is circulated at a rate of 100 gpm; therefore, there is a turnover of water in the system every 2 1/2 minutes. This should allow for a warm-up time of less than 25 minutes.

Since this is a closed loop system, it should not be necessary to provide water treatment. An initial fill of boiler feed water or condensate would put the system in operation. Condensate from the steam jet heater will gradually add more water to the system.

The excess water will overflow into a separate 150-gallon tank to be used for the purging of lines when it is necessary.

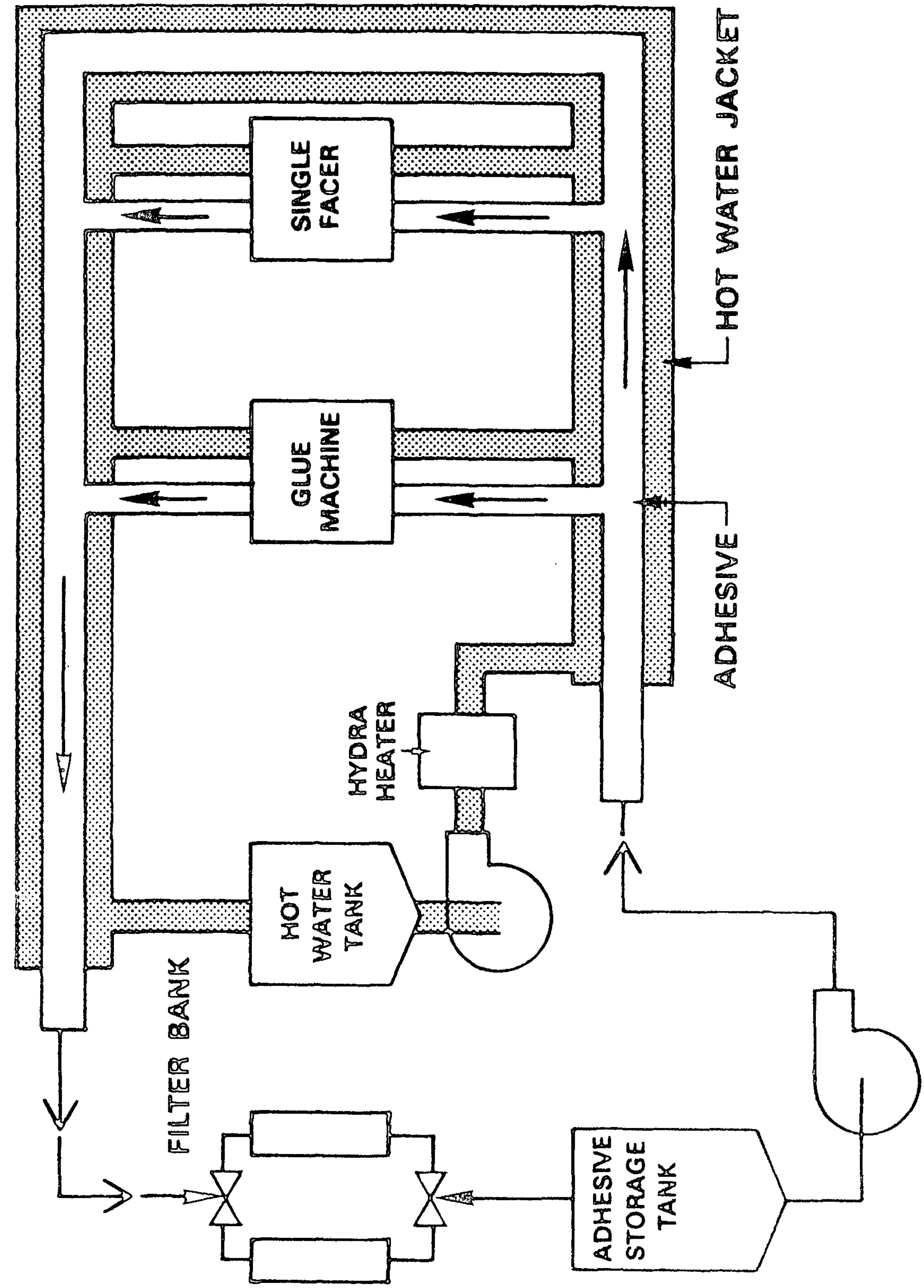


Figure B11. Adhesive and Hot Water Distribution System

Instrumentation

In addition to the instrumentation mentioned for control, which will be monitored by the data acquisition system, additional instrumentation will be supplied to monitor other variables. These include the following:

1. Slurry storage tank temperature.
2. Slurry pH after the AP addition.
3. Steam pressure into cooker.
4. Cooker back pressure.
5. Slurry flow rate.
6. Adhesive storage tank level.
7. Adhesive pH after the caustic addition.
8. Rate of caustic addition.

DATA ACQUISITION SYSTEM

General Design

An important task in the commercial evaluation of the cold process is a thorough mapping of the equipment design and the cold corrugating process. Data from trial runs are necessary to provide a definitive assessment of cold corrugation performance and advantages and information for second generation equipment design.

To assist in this evaluation, a data acquisition system, capable of on-line monitoring of all of the variables which can affect equipment performance and board quality, is incorporated. Sensors for monitoring these variables are used on all of the equipment. Two remote conditioning stations are used to collect the information from the sensors, convert the signals to digital form, and send them to the central computer. The central computer serves three major functions: it processes and stores data for later analysis, updates four operator display stations, and produces reports as required. The operator display stations are located at the single facer, in the glue machine-adhesive system area, in the central computer room, and at the slitter-scorer. These stations display to the operator the current values of the variables being monitored. Figure B12 illustrates the data acquisition system.

It should be noted that the computer is being used strictly in a data acquisition mode and not for corrugator control. In fact, all variables needed for corrugator operation are also displayed independent of the computer system so the system can be operated without the computer.

The initial intent was to purchase the data acquisition system on a turnkey basis. Further analysis of the situation revealed a very real problem with coordinating the computer hardware, software development, sensor selection, and corrugating equipment suppliers. Further problems were anticipated with system responsibility after the equipment was installed. For this reason, all of the computer hardware was purchased from a single vendor and IPC personnel have developed the software and selected the sensors unique to the project.

Sensors

Four classes of sensors are used in the cold corrugating system. These are defined below and listed on subsequent pages.

1. Class 1 -- Those sensors utilized only by the data acquisition system, e.g., liner and medium moistures. These sensors were furnished by IPC and mounted and wired to a suitable junction box for connection to the data acquisition system by the equipment supplier.

2. Class 2 -- Those sensors utilized by both the data acquisition system and the equipment manufacturer's control system, e.g., liner and medium tensions. These sensors were furnished, mounted, and wired to a suitable junction box for connection to the data acquisition system by the equipment supplier.

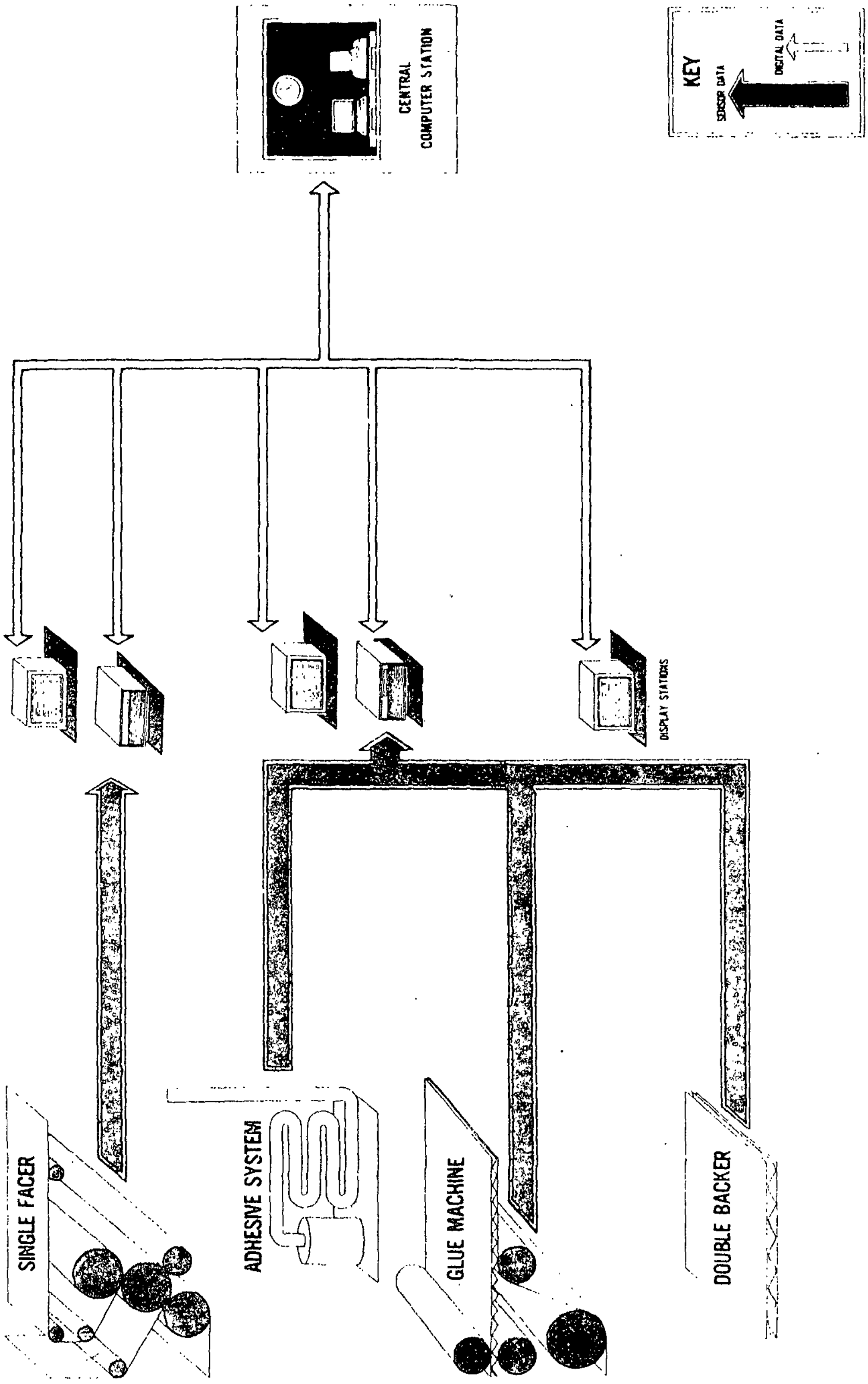


Figure B12. Data Acquisition System

3. Class 3 -- Those sensors necessary for machine operation should the data acquisition system not be functioning or as a supplement to it. This class includes all variables normally used in the operation of the corrugating euqipment, e.g., a pressure gauge monitor of the corrugating roll load. These sensors were furnished and installed by the equipment supplier.

4. Class 4 -- Those sensors for the measurement of energy consumption. These sensors were furnished by IPC and installed by Union Camp.

Class 1 Sensors

Sensor Number	Sensor	Location
1	Medium speed	Single Facer
2	Medium temperature	Single Facer
3	Medium moisture	Single Facer
4	Liner speed	Single Facer
5	Liner temperature	Single Facer
6	Liner moisture	Single Facer
7 & 8	Adhesive application rate*, instantaneous application rate, lb starch/MSF	Single Facer
9 & 10	Top corrugating roll load, (drive and operator's side)	Single Facer
11 & 12	Pressure roll load, (drive and operator's side)	Single Facer
13	Adhesive temperatures at delivery to transfer roll	Single Facer
14	Adhesive system water jacket temperature	Single Facer
15	High-low monitor*	Glue Machine
16	Single face moisture	Glue Machine
17	Single face temperature	Glue Machine
18	Double face liner temperature before double backer	Glue Machine
19	Double face liner moisture before double backer	Glue Machine
20 & 21	Adhesive application rate*	Glue Machine
22	Adhesive temperature	Glue Machine
23	Adhesive water jacket temperature	Glue Machine
24 & 25	Moisture scanning gauges (top and bottom)	Double Backer
26 & 27	Temperature scanning gauges (top and bottom)	Double Backer
28	Slurry temperature	Adhesive System
29	Slurry pH	Adhesive System
30	Steam pressure into cooker	Adhesive System
31	Supply water jacket temperature	Adhesive System
32	Return water jacket temperature	Adhesive System
33	Supply adhesive temperature	Adhesive System
34	Return adhesive temperature	Adhesive System

* Developed under separate projects.

Class 2 Sensors

Sensor Number	Sensor	Location
35	Medium tension	Single Facer
36	Liner tension	Single Facer
37	Bridge stock	Single Facer
38	Medium treatment application, off/on	Single Facer
39	Medium width	Single Facer
40	Single face tension	Glue Machine
41	Double face liner tension	Glue Machine
42	Rider roll gap or loading	Glue Machine
43	Combined board caliper	Double Backer
44	Combined board speed	Double Backer
45	Adhesive pH after caustic addition	Adhesive System
46	Rate of caustic addition	Adhesive System
47	Cooker back pressure	Adhesive System
48	Slurry flowrate	Adhesive System
49	Adhesive storage tank level	Adhesive System

*Class 3 Sensors

50	Adhesive system water jacket temperature	Single Facer
51	Adhesive temperature	Single Facer
52	Adhesive system water jacket temperature	Glue Machine
53	Adhesive temperature	Glue Machine
54	Slurry storage tank temperature	Slurry Area
55	Slurry make-up tank level	Slurry Area
56	Slurry storage tank level	Slurry Area
57	Steam pressure	Adhesive System
58	Cooker back pressure	Adhesive System
59	Level in adhesive storage tank	Adhesive System

Class 4 Sensors

60	Steam consumption, cooker	Adhesive System
61	Steam consumption, water heater	Adhesive System
62	Electrical consumption, single facer	Single Facer
63	Electrical consumption, double backer	Double Backer
64	Electrical consumption, dry end equipment	Double Backer
65	Electrical consumption, remainder of system	Glue Machine

* To be included along with Class 3 sensors are all those which would be furnished with a conventional corrugating system.

Web speeds are sensed by Madison Electric digital tachometers mounted on idler rolls.

Conax roller tip temperature probes are used for sensing temperatures of the moving webs. This is a thermocouple-based sensor.

Moisture is being monitored by Delmhorst finger-type probes. Moisture percentage is determined by the change in resistance with the change in moisture content. The probe being used measures surface resistance and therefore is not greatly affected by varying basis weights. Initial tests indicate that different paper grades do not have a great affect either. Over a wide range of paper grades, moisture contents, and basis weights, there was a correlation coefficient of 0.89 between the probe readings and moisture contents determined by weighing and oven drying the samples.

Many of the sensors are mounted on manual positioning bars so they can be positioned at any desired location across the machine.

On the table at the exit of the double backer, there will be an automatic scanning system interfaced to the computer. Moisture and temperature sensors for both the top and bottom of the combined board will be included. At preselected intervals, the computer will initiate a cross-machine scan. The information obtained in this scan will be stored and also presented graphically to yield moisture and temperature profiles of the board.

Adhesive application rates are measured by a pair of Micro-Motion mass flow meters. These meters sense the flow into and out of the adhesive use stations. The computer uses these two readings combined with liner speed, web width, and percent solids of the adhesive to calculate the application rate in lbs/MSF.

For monitoring the pressure loading of the corrugating, pressure, and rider roll, Robinson-Halpern potentiometric pressure transducers are used.

Omega type J industrial thermocouples are used for monitoring adhesive, slurry, and water temperature.

A Selcom Optocator, a laser-based height sensor, along with electronics developed at IPC, are used for detecting high-lows of the single face web.

Proportional sensing of adhesive level in the return sumps is accomplished with Drexelbrook level sensors. These sensors work on an admittance principle and are supposed to be unaffected by build-up on the probe.

The steam flows are monitored with orifice plate/differential pressure cell units.

Remote Conditioning Stations

There are two remote conditioning stations in the data acquisition system, one located at the single facer, the other in the glue machine/adhesive system/double backer area. These stations collect low level signals in various forms from the sensors, condition and convert them to digital form, and transmit the digital values to the central computer. Each station stores the data from the sensors and then, on command, transmits them to the central computer in a burst.

Macsym 20 remote measurement and control systems from Analog Devices are used as the remote conditioning units. Each has provisions for 16 input conditioning modules and each module is capable of accepting 16 or more sensors. These modules provide the conditioning necessary to accommodate various signal forms such as voltage, current, thermocouple, frequency, or strain gauge signals. The Macsym 20 has an internal 12-bit analog to digital converter with programmable gain up to 2,048.

The unit is equipped with a Z80A microprocessor and 16K bytes of RAM memory. The microprocessor is programmed in a BASIC-like program. This programmability allows the unit to scan the sensors, convert the inputs, and store the results in memory without any intervention from the central computer. Upon request from the central computer, the stored data will be transmitted over an RS 232C interface in a burst fashion. The programmable feature in the remote stations frees the central computer for other tasks.

The Macsym 20 would normally be hard programmed with EPROM memory, but because of the interface to the central computer, programs can be down loaded from the central computer and stored in the RAM memory. This allows easy modification of programs as necessary.

Central Computer

The central computer collects the data from the remote conditioning stations, converts it to engineering units, checks for out of limit variables, sends present values to the Operator Display Stations, and stores the values for later use. As background tasks, the computer can analyze current or past data, provide reports to be used in conjunction with laboratory test results, and prepare either graphical or numerical reports.

The central computer is located in an elevated enclosure in the knife-stacker area. This position allows the operator and test personnel to view the entire corrugator while monitoring the computer. It also avoids use of floor space needed for other functions.

A Macsym 2 from Analog Devices was selected for the central computer. This is a 64K minicomputer with an interactive BASIC disk operating system.

Peripherals included with the system are a dual floppy disk drive, cartridge tape system, Tektronix 4006 CRT graphic display with keyboard, Tektronix 4662 digital X-Y plotter, and a Data Royal 80 column printer. All of the equipment was purchased as a system from Analog Devices to simplify interface and maintenance requirements. The CRT display with a keyboard serves as the principal input/output device for programming and operator interaction.

The disk system serves as main storage medium for process data. A new disk can be used for each day's running and the old disks retained so that the data can be retrieved for analysis as needed. The disk also serves as the system and program storage unit.

The graphic CRT terminal is used for viewing data in either an alph-numeric or graphical mode. This allows rapid screening of stored information.

Hard copy reports of alphanumeric data are obtained on the printer whereas the X-Y recorder is used for graphical presentations. A printed output of corrugator conditions for each test will be available, including blank areas for the recording of laboratory test data.

Operator Display Stations

The four operator display stations are located at the single facer, in the glue machine/adhesive system, at the central computer station, and at the slitter scorer. Ball CRT terminals were selected for this purpose. The function of the stations is to keep the operator informed of conditions on the corrugator line. Current values of the monitored variables are displayed and constantly updated. Variable values which fall outside of preset ranges are highlighted to attract the operator's attention.

Summary

As of this writing, all cold corrugating equipment except the double backer is installed in the plant. Satisfactory mechanical operation of the double backer has been demonstrated in the S & S shop and the unit will now be disassembled, painted, and shipped to Savannah. Installation will take place when the remainder of the system is operating satisfactorily.

All of the installed equipment remains in a start up mode although the adhesive system is very nearly in final form. Single facer performance is encouraging although longer and higher speed runs are needed for a true test. Although the ultimate performance of the glue machine indexing system is yet to be determined significant progress has been made. Speed variations and differences in top and bottom belt speeds in the old double backer are potential trouble spots under active investigation. In the data system, some sensors remain to be checked. System performance and function has been good; reliability has been somewhat disappointing.

The near future should see the production of satisfactory combined board via the cold process on this new system. Detailed evaluation will then follow.

APPENDIX I - MATERIALS AND PROCEDURES

MATERIALS

Four 26 lb (ca. 127 g/m^2) mediums were selected for evaluation in the main parts of the study as follows:

1. Roll No. 1, semichemical
2. Roll No. 10, semichemical
3. Roll No. 19, semichemical
4. Roll No. 114, recycled fiber

Sample rolls 10 and 114 exhibited comparable flat crush levels under both hot and cold corrugating conditions. Sample rolls 19 and 1 exhibited lower flat crush under cold conditions than under hot conditions.

CORRUGATING

Each roll was corrugated in the Institute's experimental corrugator under both hot and cold conditions. In the "hot" runs the corrugating rolls and preconditioner were maintained at 350°F and the steam showers were used.

In the cold runs the preconditioner and corrugating rolls were at room temperature. The mediums were treated on both sides prior to the labyrinth with a solid "slip" agent comprised of paraffin wax, graphite, stearin, and silicone oil.

In other studies with these mediums single-faced board samples were taken at speeds up to 600 FPM at minimum web tension. For this study additional samples of (1) the formed but unglued medium and (2) single-faced board were obtained at a speed of 200 FPM under both hot and cold conditions.

TEST PROCEDURE

The uncorrugated mediums were characterized in terms of a wide array of physical properties as shown in Table IV. The STFI compression test was developed at the Swedish Forest Products Laboratory by Cavlin and Fellers (28). The Weyerhaeuser lateral support apparatus was described by Stockman (31).

TABLE V

PROPERTIES OF THE UNCORRUGATED MEDIUM

Property		Roll 10		Roll 114		Roll 19		Roll 1	
		Eng. Units	SI Units	Eng. Units	SI Units	Eng. Units	SI Units	Eng. Units	SI Units
Basis weight, lb/M ft^2 (g/m^2)		26.0	126	28.2	136	26.3	127	26.1	126
Caliper, mil (μm)		10.2	259	10.8	274	10.7	272	9.2	234
Density, lb/m ft^2-mil (kg/m^3)		2.55	486	2.61	496	2.46	467	2.84	538
Concora crush, lb, N (CMT)		52.2	232	66.7	297	63.7	283	76.8	342
Coeff. of friction[a]	73°F	--	0.58	--	0.52	--	0.54	--	0.54
	310°F	--	0.44	--	0.24	--	0.25	--	0.28
Edgewise compression, lb/in. (kN/m)									
STFI compression,	MD	18.9	3.31	22.5	3.94	20.9	3.66	23.3	4.08
	CD	11.6	2.03	12.1	2.11	13.4	2.34	12.2	2.14
Weyerhaeuser comp.[b],	MD	12.5	2.19	14.7	2.57	15.3	2.68	17.8	3.12
	CD	8.2	1.43	7.3	1.28	10.3	1.81	9.8	1.71
Tensile strength, lb/in. (kN/m)									
	MD	25.8	4.52	53.6	9.38	34.9	6.11	43.2	7.56
	CD	13.1	2.29	17.5	3.06	17.0	2.98	14.9	2.61
Ultimate strain, % Tensile	MD	0.94	--	1.42	--	1.22	--	1.04	--
	CD	1.30	--	4.24	--	1.79	--	2.57	--

TABLE V (continued)

PROPERTIES OF THE UNCORRUGATED MEDIUM

Property		Roll		Roll 114		Roll 19		Roll 1	
		Eng. Units	SI Units	Eng. Units	SI Units	Eng. Units	SI Units	Eng. Units	SI Units
Compressive[b]	MD	0.41	--	0.37	--	0.45	--	0.42	--
	CD	0.59	--	0.58	--	0.59	--	0.67	--
Et stiffness, lb/in. (kN/m)									
Tensile,	MD	3770	660	6176	1080	4360	760	5410	950
	CD	1730	303	1791	313	2100	368	1810	317
Compressive[b]	MD	3440	602	4660	816	3920	687	4660	816
	CD	1740	304	1650	289	2050	359	1810	317
ZDT strength, psi (kPa)		64	440	62	430	69	480	85	590
VVP bonding[c], kp-cm/sec		--	614	--	680	--	548	--	450
Porosity (Bendtsen), ml/min		--	332	--	909	--	846	--	958
Smoothness (Bendtsen), ml/min									
	Felt side	--	2999	--	3126	--	2813	--	2548
	Wire side	--	2931	--	3171	--	2705	--	2663
Water drop, sec		--	27	--	36	--	554	--	86

[a]Kinetic friction between steel and medium surfaces.
[b]Weyerhaeuser lateral support apparatus and method.
[c]Determined using IPC bonding strength test (rupture endpoint).

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