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REVIEW OF 1970-1971 ACTIVITIES AND SUGGESTED AREAS FOR FUTURE WORK

✓ Project 2906

Report Three

A Progress Report

to the

FIBRE TUBE AND CORE RESEARCH GROUP

January 15, 1972

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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REVIEW OF 1970-1971 ACTIVITIES AND SUGGESTED AREAS FOR FUTURE WORK

INTRODUCTION

In 1970, companies concerned with the manufacture and sale of fiber tubes, cores and cans initiated a research program at The Institute of Paper Chemistry. The broad objectives of the program were to develop basic information relative to the following:

1. Properties needed in tubes and cores to give maximum performance in a given use environment.
2. The type and level of properties needed in the base stock to obtain a designated level of end-use performance.
3. The effect which the variables of design, construction, fabrication, etc., have on tube and core performance so that the significant variables can be controlled.
4. The most efficient wall composition for a given size and design of tube or core for maximum performance.
5. The effect of the type and amount of adhesive on performance.
6. Methods of evaluating tube and core performance more adequately in terms of field or end-use performance.

These objectives, when considered in light of the many types of tubes and cores, were beyond the scope of a two-year research program. Accordingly, the research program for the initial period was designed so as to embrace those areas of the overall program which were of immediate interest

and on which reasonable progress could be made. Thus, the initial program was directed to the study of (a) tube and core performance under various types of loading and (b) the development of relationships between tube and core performance, tube and core dimensions, and the properties of the core stock.

This report summarizes briefly the progress made in the initial contractual period. It also outlines a number of topics which the sponsoring companies may be interested in pursuing on a continuation of the program.

REVIEW OF ACTIVITIES DURING 1970-1971 CONTRACTUAL PERIOD

For purposes of the following discussion, research activities are briefly summarized under the following subjects:

1. Review of literature on tube and core performance.
2. Effect of core stock properties on tube and core performance (Phase I).
3. Effect of core dimensions on core performance (Phase II).

REVIEW OF LITERATURE ON TUBE AND CORE PERFORMANCE

A search of the literature pertaining to fiber tubes and cores revealed that the literature is almost exclusively directed to patents covering equipment design and processing or the composition of the cylinder wall. Only a limited number of references were found which were directly concerned with the structural performance of tubes and cores and the relationship of core performance to the properties of the core stock. The latter references were discussed in Report One and were supplemented with a brief review of the structural aspects of the axial crush, side crush, beam and torque tests on cores. These are discussed in the following sections.

In view of the above it appears that a review of the literature pertaining to methods of manufacture, design, and construction of cores may be of interest.

EFFECT OF CORE STOCK PROPERTIES ON CORE PERFORMANCE (PHASE I)

The objective of this phase was to investigate the relationship between tube and core performance and the properties of the core stocks. For this

purpose, twenty-one samples of core stocks were obtained from the participating companies and made up into three-inch diameter cores. The wall thickness was nominally 0.270 inch and the angle of wind was approximately 58° .

Analysis of the data indicated the following:

1. The edgewise compression strength of the core stock at (a) the effective orientation as a function of the wind angle or (b) the C.D. direction was the property most highly correlated with each core performance test. This indicates that attention should be directed toward means for developing edgewise compression strength in the manufacturing of core stock in the most economical manner. Among the papermaking factors which are known to affect edgewise compression strength are weight, degree of refining and wet pressing, fiber furnish, degree of restraint during drying, and certain chemical additives such as guar, polyethylenimine, etc.

2. The axial crush, beam strength, and torque strength tests were highly intercorrelated. This implies that these three performance tests are primarily dependent on the same property of the core stock — in this case edgewise compression strength.

3. Side crush was also highly intercorrelated to the other core tests though to a somewhat lesser degree. Thus, side crush strength is probably primarily dependent on the same property of the core stock as the other core stock tests.

4. Other properties generally exhibiting high correlations with core performance included tensile strength, tensile stiffness, and ply-bond.

5. The edgewise compression test employed in this study was a modified version of the ring compression test. In general, edgewise compression tests require considerable care in specimen preparation and tester calibration and adjustment. In view of this it may be desirable to consider using relationships between modified ring strength and other properties such as tensile stiffness and ply-bond which may be easier to measure. Report Four shows that fairly good predictions of modified ring strength can be obtained using either tensile strength and ply-bond or tensile stiffness and ply-bond. Further work to better define such relationships is recommended.

6. Based on structural theory, equations were developed in Report One to predict core strength from (a) the edgewise compression strength of the core stock, and (b) the diameter and thickness of the core. The appropriateness of the dimensional factors was then checked using data generated in Phase II -- effect of core dimensions. This work is discussed in Report Two and is summarized in the next section.

EFFECT OF CORE DIMENSIONS ON CORE PERFORMANCE (PHASE II)

For the second phase, cores were fabricated from two core stocks with inside diameters of 1.5, 3, 6, and 10 inches and nominal wall thicknesses of 0.15, 0.27, 0.48, and 0.66 inch. The winding angle was 68° for the 1.5, 3, and 6-inch diameter cores and 77° for the 10-inch cores. The cores were evaluated for axial crush, side crush, and beam strength. The following conclusions were reached:

1. Analysis of data indicated that the structural formulas proposed in Report One did not adequately account for the effect of winding angle,

diameter and thickness on axial crush, side crush, and beam strength. Modified equations were statistically derived as shown in Table I. Good agreement between observed and predicted values was obtained with the modified equations.

2. Core performance appears to be affected to a greater extent by winding angle than would be expected from the edgewise compression strength measured in the proper orientation relative to the winding angle. This may occur because failure almost invariably occurs along the spiral path defined by ply gaps. In general, for a constant diameter and wall thickness, a lower winding angle (and hence wider ribbon width) gave higher beam strength and axial crush than expected on the basis of edgewise compression strength. Side crush strength decreased with decreased winding angle but not as much as expected on the basis of edgewise compression strength.

The above is based on rather limited evidence because winding angle was not varied systematically in Phases I and II. In fact, only two comparisons of winding angle effect were possible as follows: (a) 3-inch diameter cores made at 58 and 68° wind angle and (b) 1.5, 3, and 6-inch diameter cores made at a 68° angle as compared to 10-inch diameter cores made at a wind angle of 77°.

Winding angle and ribbon width govern the advance of the core during manufacture. Hence, they affect production speed and presumably manufacturing cost. For this reason it is believed that the effect of winding angle and ribbon width on core performance should be studied further.

3. Because torque strength was not determined for the Phase II cores it was not possible to check the effect of dimensions on torque strength.

TABLE I
PREDICTION EQUATIONS FOR AXIAL CRUSH, SIDE CRUSH, AND BEAM STRENGTH

	Prediction Equation	Average Prediction Error, %a
1. Axial crush	$P_a = \frac{\pi(D_o^2 - D_i^2)P_{m\alpha}}{4h_c} [-0.03116 + (0.03573)D_i + (0.24916)(n+1)h_c + (1.45741) \cos \alpha]$	7.02
2. Beam strength	$P_b = \frac{\pi(D_o^4 - D_i^4)P_{m\alpha}}{8LD_o h_c} [0.45540 - (0.00717) L/D_i + (0.49133)(n+1)h_c + (0.00184) L + (1.28887) \cos \alpha]$	5.78
3. Side crush	$P_s = \frac{1.398 (n+1) P_{m\theta}}{(1 + \frac{D_i}{(n+1)h_c})(1 - \frac{2}{n+1})} [-0.04033 + (0.08236)D_i - (0.66127)(n+1)h_c + (1.62042) \cos \alpha]$	8.38

^aBased on observed values for Phase I and II as reference.
Note: Symbols are as follows:

P_a = axial crush, lb.
 P_b = beam strength, lb.
 P_s = side crush, lb.

D_i = inside core diameter, in.
 D_o = outside diameter, in. = $D_i + 2(n+1)h_c$
 n = number of core stock plies
 t, h_c = core wall thickness and core stock thickness, respectively, in.
 L = beam span, in.

$P_{m\alpha}, P_{m\theta}$ = modified ring compression strength at α and $90 - \alpha$ degrees, respectively, lb./in.
 α = angle of wind, degree

The equations (Va, Vb, VI) shown in Report One may be used to estimate torque strength for cores of various dimensions. However, it appears likely that, for best agreement with observed torque strength, modifying factors should be introduced as for axial crush, etc.

4. With regard to the placement of "high" and "low" strength stocks in the core wall it is believed that the maximum effect would be observed in the case of side crush. Placement of the high strength plies near the outside should give higher side crush strength than the reverse arrangement. Beam strength may also be improved with the "high" strength plies on the outside, although the effect would probably be less than on side crush. Work in this area may be of interest to the group.

5. The above equations do not take into account such factors as fabrication quality, type or amount of adhesive, etc. Such factors may affect strength and should be considered as candidate subjects for future work.

FUTURE WORK

It is believed that good progress has been made in relating core strength to core dimensions and core stock properties. Hence, future work should focus attention on other subjects of general interest to the group. A number of possible subjects for future work are briefly outlined below and it is hoped that additional suggestions relative to the direction of future work will be made by members of the group. Based on the preferences of the group, a detailed proposal for future work will be prepared by the Institute.

1. Effect of winding angle and ribbon width on core performance.

Based on limited evidence, the present study has indicated that core performance is affected to a greater extent by winding angle and ribbon width than would be expected from the change in edgewise compression strength with test orientation. Because winding angle and ribbon width affect production speed and, presumably manufacturing cost, it is believed that a systematic study of their effects on core performance would be of value. This would involve fabricating cores of a given diameter using a number of different winding angles and, hence, ribbon widths.

2. Study of the effect of various "papermaking" factors on the edgewise compression strength and related properties of core stock.

The present study indicates that the edgewise compression strength of the core stock is the property best related to core performance. Thus, a study of the effect of various "papermaking" variables on edgewise compression strength would be of value in assessing ways of obtaining a

given level of edgewise compression strength at minimum cost. Such a study could be carried out using handsheets. The variables to be studied would include the following: degree of refining, wet press pressure, chemical additives, drying temperature, degree of restraint during drying, etc.

3. Effect of core stock strength distribution on core performance.

The present study has indicated that cores made from various grades -- e.g., low, normal, and high strength -- exhibit substantial differences in performance. Accordingly, cores made by combining plies from one or more grades will exhibit wide differences in performance depending on the number of plies of each grade, their relative strength and their location in the core wall. While material costs will vary in proportion to the number of plies of each grade, core performance as in side crush will depend on ply placement to some extent. Hence, material costs for achieving a given level of core performance may be minimized by making the most efficient use of the material. In view of this it is proposed that a study be carried out to determine how core stock strength should be distributed in the core wall to obtain a given level of performance at least cost.

4. Effect of type and amount of adhesive on core performance and dimensional stability.

The structural performance of cores is dependent on the degree of bonding between plies. Lack of adequate bonding impairs the integrity of the structure and may drastically lower core strength. The degree of bonding will be affected by such factors as (1) type of adhesive, (2)

amount applied, (3) application conditions such as temperature, manner of application, etc., (4) nature of the surfaces being bonded, etc. In view of the above a study of the effect of type and amount of adhesive on core performance is suggested. Types of adhesive might include PVA, silicate and dextrin. Amount of adhesive would be varied over as wide a range as practical using several core stocks with differing degrees of sizing, roughness, and adhesive receptivities.

5. Effect of core stock checking on core performance.

During winding the core stock is normally drawn over relatively small diameter rods and usually exhibits relatively severe checking due to being bent over the rods. Limited data indicate that the checking substantially reduces the edgewise compression strength of the core stock. This may indicate that the inherent strength potential of the core stock is not being utilized due to the deleterious effect of checking. It is possible, however, that the effect is mitigated to some extent by the filling-in of checked areas by adhesive. It is suggested that a study be carried out to investigate the effect of checking on core performance to determine if a significant degradation of the strength potential of the core stock occurs.

6. Development of radial compression test for cores.

In many applications a core is subjected to nearly uniform radial stresses tending to cause the core to collapse due to the external pressure. An example of this occurs when a web of another material is tightly wound on a core. The side crush test does not closely simulate this type

of use condition because of the line type loading employed. It is suggested that a test method be developed for evaluating the compressive strength of cores subjected to a uniform external pressure. In broad terms this study would involve (a) development of procedures for sealing off the ends of the core, (b) construction of a suitable pressure vessel for enclosing the core, and (c) providing means for applying pressure and recording the pressure at failure. The effect of test variables such as rate of loading would be studied as well as the effect of core dimensions on failure pressure.

7. Effect of ply-gap width on core performance.

A manufacturing variable in the winding of spiral cores is ply-gap width. Normally the plies are incremented in width from inside to outside so as to close the gaps between plies or to control them within reasonable limits. Each ply gap produces a discontinuity in the structure and, stress concentrations should be induced in the vicinity of the gap. In the various core performance tests the failure zone generally follows one or more of the spiral paths defined by the ply gaps — i.e., failure does not occur at random in the test length. Thus, it appears that the widths of the ply gap may be a significant variable affecting core strength. In view of the above it is proposed that a study be directed toward determining the effect of ply-gap width on core performance. For this purpose it is suggested that cores be fabricated to permit comparisons of the following type: (a) all gaps closed vs. normal practice, and (b) all gaps closed vs. two levels of gap width.

8. Effect of number of plies on core performance.

The number of plies in a core wall of given thickness will depend on the caliper(s) of the core stocks employed. For example, 10 plies of 0.030-inch stock or 20 plies of 0.015-inch stock could be used to make up a 0.30-inch wall thickness core. It is believed that the performances of the resulting cores would differ because of (a) the different number of plies involved, (b) the different amounts of adhesive incorporated in the two cores, and (c) the relative strengths of thick and thin core stocks. The production costs of the two cores would also be different depending on the relative costs of the stocks, adhesive consumption, slitting and conversion costs. In view of the above, a limited study is proposed to determine the extent to which core performance is affected by differences in number of plies. For this purpose, it is proposed that core stocks be manufactured at "normal" density levels and approximate calipers of 0.015, 0.020, and 0.030 inch. This would permit winding cores at several thicknesses with the number of plies varying in the ratios: 2:1.5:1.0.

9. A study of the relationship between edgewise compression strength, ply-bond strength and the stiffness on tension (or compression) of core stock.

The present study has shown that core performance is primarily dependent on the edgewise compression strength of the core stock. The results have also indicated that edgewise compression strength is fairly well related to extensional stiffness and ply-bond strength. Studies in other areas relative to the effect of process variables on edgewise compression strength have shown that, with the exception of basis weight, edgewise compression is only weakly influenced by many process variables.

There is also evidence which indicates that at "low" levels of bonding edgewise compression strength is fairly sensitive to increases to ply-bond strength which is a measure of the fiber-to-fiber bond strength in the thickness direction. However, as the ply-bond strength is increased, a level is reached above which the edgewise compression strength is not markedly affected by increases in ply-bond strength.

The above and other considerations suggest that edgewise compression strength is dependent on (a) the compression-bending-buckling strength of fiber segments in the sheet network, and (b) the strength and number of bonds between fibers. Accordingly, it is proposed that a study be undertaken to enhance our understanding of the mechanisms involved in edgewise compression failure. Such information should be useful in suggesting better ways of improving the compression potential of core stock. Such a study would involve evaluation of the compression, tension and ply-bond behavior of specially prepared handsheets. The properties of the handsheets would be varied using various bending or debonding agents, drying restraints, variations in fiber length, etc.

10. Survey of literature on manufacture, design and uses of fiber cores, tubes and cans.

It is suggested that a survey of the literature relative to the manufacture, design and uses of fiber cores, tubes and cans be carried out. This would provide a ready source of reference to articles and patents dealing with manufacturing methods, special core wall constructions, means for improving core strength, etc.

11. Investigation of the mechanisms of failure involved in core performance tests.

The present work has indicated that statistical modifications were required for the sample structural formulas to obtain satisfactory predictions of core performance. This is not surprising in view of the spiral construction of the cores, the wide ranges of dimensions involved, inelastic failure phenomena, etc. In the side crush test, for example, it seems likely that shear effects are probably of considerable importance in the performance of small diameter thick-walled cores. Also, the degree of flattening of the core under load is quite dependent on diameter. In view of the above it is suggested that a study be initiated to investigate the mechanisms of failure involved in cores under load. It is suggested that side crush behavior should be investigated first using experimental stress analysis techniques to determine the nature and magnitude of stresses developed in the core wall under load.

12. Preparation of core performance nomographs, graphs, etc., to facilitate estimation of core strength.

It is suggested that nomographs be prepared to facilitate estimation of core strength from the properties of the core stock and dimensions. This would have the benefit of making the equations developed in the present study more convenient to use.

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A handwritten signature in dark ink, appearing to read 'W. J. Whitsitt', written over a horizontal line.

William J. Whitsitt
Research Associate
Container Section

A handwritten signature in dark ink, appearing to read 'Robert C. McKee', written over a horizontal line.

Robert C. McKee
Chairman
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