

Corrugated medium strength assessments in different flute structures

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ABSTRACT: Recent advancements in our ability to evaluate papers and our understanding of the mechanics of box failure have brought a renewed focus on measuring the performance of corrugated medium and an associated evolution of paper measurement approaches. This study evaluates the load curves, Hardness (where the fluted structure's loading shifts away from an elastic response), and Concora medium crush test (CMT) values for a range of corrugated mediums in different common flute geometries.

The shape of the load curve is a function of the geometry of the fluting profile and the relative stiffness of the paper, with smaller flutes and heavier papers reaching both the Hardness value and the ultimate load at lower deformation. Nonetheless, while the specific dynamics during the loading process vary, Hardness and CMT values correlate linearly between flute structures, even when testing specimens after different equilibration periods post-fluting. These correlations confirm the applicability of the standard A-flute CMT test to a broad range of papers and potential combined board flute structures, supporting quality assurance processes for medium production and optimization in corrugated board manufacturing.

Application: Given the proliferation of test methods assessing corrugating medium, this work helps those measuring paper performance understand how the different tests may relate in order to help focus the properties that a researcher or quality department may need to assess.

Corrugated boxes are made from two components, linerboard (liner, facing) and medium (fluting), each designed for a different purpose. Linerboard, which forms the facing of the typical corrugated package, contributes to box performance through its cross-machine direction (CD) strength and supplies the bulk of the compression strength (edge crush strength [ECT]) of the combined board from which the box is constructed. This cross-directional strength is usually specified either using ring crush (RC; TAPPI Standard Test Method T 822 “Ring crush of paperboard [rigid support method]”) or short span compression test (SCT or STFI; TAPPI T 826 “Short span compressive strength of containerboard”) [1-6]. Linerboard also contributes to the bending resistance of the board and provides resistance to scuffing and puncturing forces that may arise through rough handling. Papermakers typically focus on the optimization of linerboard CD strength relative to its basis weight [7-11], leading to the industry's current range of lighter weight performance liners to meet the stacking requirements of a modern distribution environment.

Corrugated medium forms the interior structural component of combined board. It contributes to the strength of the board and box through its CD properties, while the machine direction (MD) strength helps the fluted structure resist z-directional crushing forces and provides structural support [12,13]. The MD properties affect not just how stiff the box is, but also how the box behaves over time under load (its elasticity and creep) [14,15]. A survey of industry

specifications highlights current perspectives on the relative importance of the medium's directional properties. Some producers specify the CD strength of their mediums, using either RC, SCT, or the cross-directional crushing resistance of a fluted sample using the fluted edge crush test (CFC; TAPPI T 843 “Fluted edge crush of corrugating medium [rigid support method]”). Other producers do not specify CD strength at all. However, all major producers specify Concora medium crush test (CMT; TAPPI T 809 “Flat crush of corrugating medium [CMT test]”) to assess the MD strength of their papers.

Long and Maltenfort introduced CMT to the corrugated industry over 70 years ago [16-17], presenting a measurable paper property that correlated with the resilience of the fluted structure in a box panel. They published tables correlating the values obtained in a CMT test on a range of papers and the values obtained for the flat crush test (FCT; TAPPI T 825 “Flat crush test of corrugated board [rigid support method]”) of A-flute, B-flute, and C-flute combined board specimens made with those papers. Additional work in support of the method was done at the Institute for Paper Chemistry [18], with the test used to both improve the manufacture of medium as well as define the combining effectiveness of the corrugating process [19].

Though the equipment for measuring compressive loads and fluting samples has changed, the fundamental structure of the traditional CMT test specimen has not. The test consists of feeding a 152.4 mm x 12.7 mm (nominal 6 in. x 0.5 in.) test specimen between two hot corrugating

rolls in a fluter (a smaller scale version of the method of forming the fluted structure on a corrugator). The typical and prescribed test orientation has the longer side parallel to the MD to mimic the fluting direction on the corrugator. The specimen is then adhered on one side to a pressure sensitive tape to maintain the spacing of the flutes during the test process and compressed between two flat platens at a rate of 12.5 mm (nominal 0.5 in.) per minute to measure the maximum load the fluted specimen can support. Because the paper strip leaves the fluter with a moisture content much lower than its ultimate equilibrium in the typical laboratory testing environment, it rapidly begins to take up moisture. The original work highlighted the importance of evaluating the material immediately (within 10–15 s, now known as CMT or CMT₀) in order to reduce the variation in test results. Subsequent studies [20–24] explored the dependence of CMT on the moisture content of the specimen and the variation in peak load values with the equilibration time allowed before testing. The fluted paper strip reaches true equilibrium after a period of hours (TAPPI T 402 “Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products,” note 5), but the moisture stops changing rapidly after 15–45 min (depending on the study). A common test procedure developed shortly after the introduction of the original CMT method involves fluting a set of specimens, adhering each to its tape, and allowing them to equilibrate in the standard laboratory environment for 30 min before testing (now known as CMT₃₀, described in ISO 7263-1 “Corrugating medium — Determination of the flat crush resistance after laboratory fluting, Part 1: A-flute”). The limited literature is inconclusive regarding how well CMT₀ and CMT₃₀ correlate and which one has lower variability.

The original CMT fluter was designed with a roll configuration similar to the A-flute rolls commonly in use at the time. As noted by Maltenfort and Long [17], the specific fluting configuration is less relevant than the repeatability of the method and its correlation with board performance. Even in the 1950s, flute configurations varied

between manufacturers due to roll size, roll wear, etc. Flute profiles have continued to evolve (Table I) [25] as corrugated manufacturers and their suppliers work together to optimize the properties and cost of combined board. This evolution has moved the correlation between the CMT values and combined board flat crush further from the initial relationship [17]. Some modern producers, concerned that the historical CMT method (TAPPI T 809 and ISO 7263-1) did not relate as well to the flat crush of modern combined board, recently developed a similar method using a smaller (B-flute) geometry (ISO 7263-2 “Corrugating medium — Determination of the flat crush resistance after laboratory fluting, Part 2: B-flute”). While there exist only limited theoretical explorations [26–28] linking CMT strength across flute structures, there is no data available in the literature relating the results of the two ISO tests or correlating either test to modern board configurations in a manner similar to the 1956 work of Long and Maltenfort.

The development of the CMT test focused on the peak load sustained by the medium before total collapse, at least in part because it was “straightforward” to measure given the equipment available. Researchers have tried to understand the mechanics of the failure theoretically based on the flute structure [29,30]. Some researchers have worked on correlating CMT with SCT values in the MD, a test that, unlike CMT, can be automated. But SCT losses in fluting depend on the corrugating process and vary across the fluted specimen and structure [31–34], making a universal correlation with an unfluted paper property challenging. Research continues to understand mechanistically what fundamental fiber and paper properties contribute to CMT performance [35].

There has also been renewed interest in the entire complex CMT load curve, not just the ultimate/peak load but also the first peak (or point of inflection) in the curve called “Hardness” where the loading of the fluted structure shifts away from an elastic response [36–42]. It has been historically challenging to measure this peak directly on typical laboratory equipment, requiring tracking of the entire stress-strain curve and then identifying the point of shift

	A-flute		B-flute		C-flute		E-flute	
Year	flutes/ft	mm/flute	flutes/ft	mm/flute	flutes/ft	mm/flute	flutes/ft	mm/flute
1956	36	8.47	51	5.98	42	7.26		
1965	36	8.47	51	5.98	39	7.82	96	3.18
1971	36	8.47	50	6.10	42	7.26	94	3.24
1992	33	9.24	47	6.49	39	7.82	90	3.39
2015	33	9.24	47	6.49	37.7	8.08	90	3.39

I. Typical/average/nominal pitch of flutes for various corrugating roll configurations as reported in different editions of the industry's Fibre Box Handbook [25]. All of the major fluting structures used by industry have shifted, and continue to shift, in both pitch and flute depth.

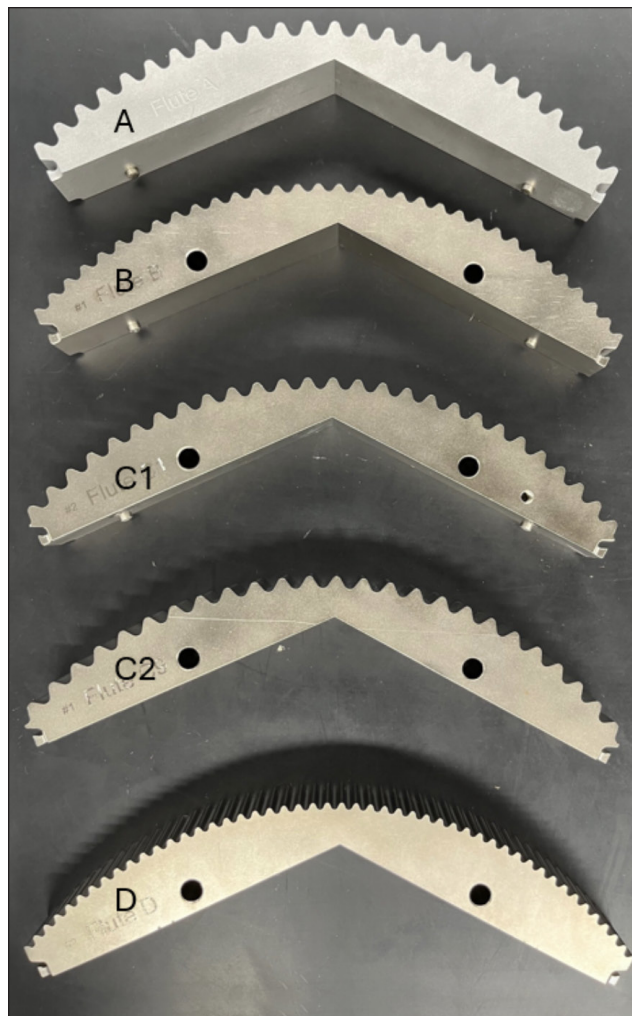
	Pitch		Depth	
Flute	flutes/ft	mm/flute	in.	mm
A	36.0	8.47	0.187	4.75
C2	36.7	8.30	0.142	3.62
C1	39.2	7.78	0.142	3.62
B	47.3	6.44	0.099	2.51
D	71.0	4.30	0.078	1.99

II. Specified pitch and flute depth for the five corrugating roll configurations studied.

from elastic behavior, but recent advances in technology and the introduction of the S-Test have revived interest in this area. It may well be that CMT (done in A-flute) correlates equally well with flat crush across fluting configurations as indicated by Long and Maltenfort, but there is no similar assessment for Hardness. The literature is also largely silent on the correlation between CMT and Hardness across different flute profiles. The CMT depends on a range of paper parameters, but it is unknown which of those might correlate with Hardness.

Some in the industry have questioned whether the standard test in A-flute truly applies to the range of combined board structures we produce today. However, the papermaker has no information available regarding the fluting structure to be created from a given roll of paper, and has limited ability to test for all possible stress applications. Loss of a general test assessing a medium's "fitness for use" would pose a particular challenge to the quality assurance process, as would the need to meet requirements set by multiple standards (c.f., ISO 7263-1 and 7263-2, along with any future versions or adaptations).

In this paper, we present results from an extended study designed to fill in some of the literature gaps identified previously, considering the increased interest by the industry in medium performance characterization. We explore CMT load curves across grades using modern equipment configured with a range of fluting structures. Comparisons of the peak load values help identify whether CMT (A-flute) is still valid as a generalized paper test and if CMT in different flute structures adds meaningful additional information. In parallel, comparison of the full load curves and the Hardness values produced from the different flute structures extends the ongoing literature discussion surrounding the mechanics of flute behavior in compression and continues the assessment of the relative merits of Hardness in comparison with CMT. Finally, since the CFC test uses the same equipment and a typical lab or mill operation is not likely to invest in multiple fluters with different geometries for different tests, we compare the results of CFC evaluations for a subset of flute configurations.



1. Pictures of various fluting arc segments used in the Frank-PTI fluter.

EQUIPMENT, MATERIALS, AND METHODS

The medium fluter used in this study (produced by Frank-PTI; Birkenau, Germany) has removable fluting segments facilitating production of fluted paper strips in different flute structures. We purchased segments in five configurations (**Table II, Fig. 1**) to enable exploration of different flute pitch and height combinations. The A-flute segments match the specifications of the CMT test standard, though not the A-flute geometry in typical use today. The C2 and C1 segments have similar flute depth but different pitch, representing two different C-flute corrugating rolls commonly in use in the North American corrugated industry. The C2 pitch is very similar to the A-flute standard, although the depths are quite different. The B- and D-flute rolls are representative of their respective current flute geometries.

For each set of flute segments, we also purchased matching "3rd hand" fixtures to facilitate the taping operation. The flute sizes smaller than A-flute produce a 6 in. x 0.5 in. fluted strip with more than ten flutes. Flutes beyond the

Material	Nominal Grade	Recycled %	Virgin Source
1	23	35%	Northern SCM Hardwoods
2	23	80%	NSSC
3	23	45%	Northern SCM Hardwoods
4	23	60%	Southern Kraft Pine
5	23	45%	Southern Kraft Pine
6	23	35%	Northern SCM Hardwoods
7	26	35%	Northern SCM Hardwoods
8	26	80%	NSSC
9	33	40%	Northern SCM Hardwoods
10	33	25%	Northern SCM Hardwoods
11	40	25%	Northern SCM Hardwoods

III. Typical furnish and “nominal grade” (U.S., in lb/MSF) of the materials used in this study.

ten-flute section were removed or crushed flat before testing; all CMT results reported here represent the force to compress ten flutes. We also purchased jigs to support CFC samples in all but the D-flute configurations to match the fluting profiles used for the CMT study.

For any test to be broadly useful, it needs to be applicable across the materials used in industry. We chose 11 materials from a range of paper machines using different forming technologies, varying in basis weight and furnish (Table III). Six of these papers would be nominally considered “23 lb medium,” the most common medium grade sold in North America. All materials were “center cut” from the paper machine production reel, minimizing the cross-machine variation in the sampled material, and were collected from a limited amount of paper in the MD, also with the goal of minimizing variation due to the input materials.

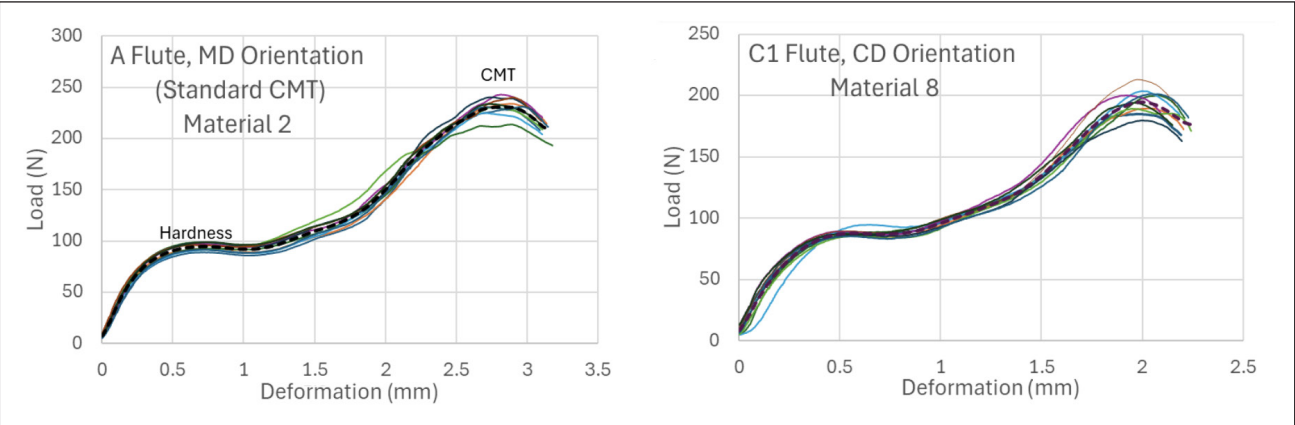
Each individual test result averages the values from fluting ten strips of paper. For each strip, we measured the full

load curve and calculated the Hardness point and CMT value. We averaged these values to produce our test result for that material (Fig. 2), calculating the peak value (CMT) and Hardness from the composite curve. The Frank-PTI crush tester used in this study outputs a “meander” point as well as the CMT values, and the meander values agree well with our calculated Hardness from the load curves [40]. We rely on those values throughout this paper. We tested each of the 11 papers for CMT₀ on strips cut in both the MD (standard) as well as in the CD direction in each of the five flute configurations and repeated the testing for CMT₃₀ in both A-flute and the C2 configurations.

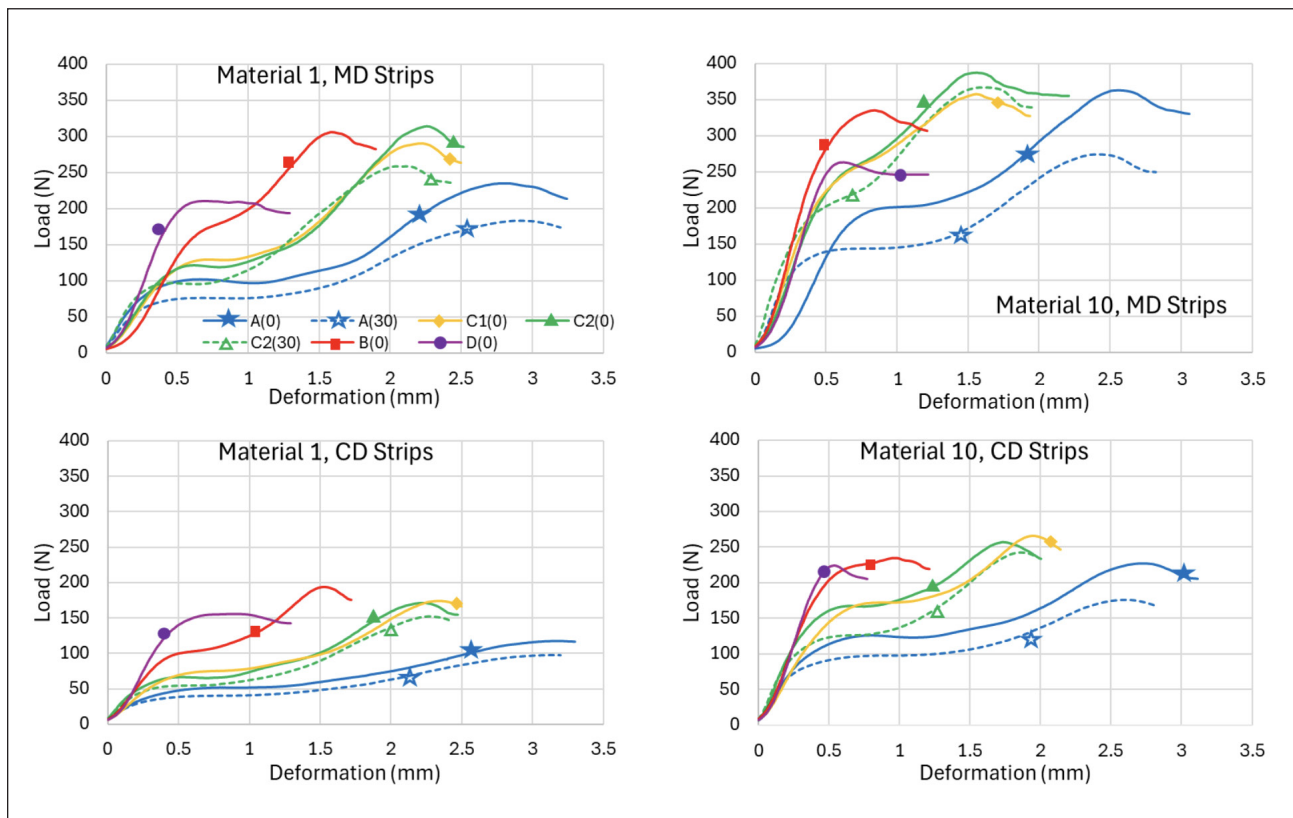
RESULTS AND DISCUSSION

Shape of the load curve

To understand how load curves change as we modify the flute structure, we can examine the composite graphs for two representative papers (Materials 1 and 10; Fig. 3). As



2. Two examples ten individual load curves (thin lines, colored individually) and the composite curve (heavier, dashed line in black) representing the average behavior of the material (MD: machine direction; CD: cross-machine direction).



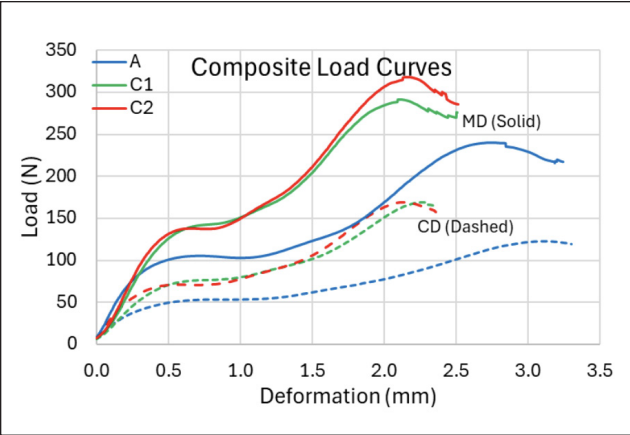
3. Composite load curves for two different materials in different flute structures and paper orientations. The CMT_0 (immediately out of fluter) curves are represented with solid lines while CMT_{30} (after 30 min equilibration in the testing atmosphere) curves are dashed (CMT: Concora corrugating medium test).

expected from the difference in fiber orientation, CD-oriented specimens carry less load than the standard (MD) specimens. The shape of the load curve is a function of the geometry of the fluting profile, with smaller flutes providing a less resilient (less cushioning) structure. Moving from A-flute to smaller flute structures, the peak load occurs at lower deformation. The CMT_{30} curves have lower load values than CMT_0 , but the general shapes are similar.

In line with expectations, heavier mediums typically produce higher CMT and Hardness values for a given flute structure, and their curves have higher initial slopes (material stiffness). We find that the deformation at Hardness is not constant; it decreases with papers of greater stiffness and changes for different flute profiles. It is not clear from this work whether this change is due to the papers themselves or whether it is an artifact of the testing process; for example, slipping of the sample on the tape adhesive causing a delay in the Hardness onset [43]. This can be studied further but is beyond the scope of our work. The lack of a fixed deformation means that if we want to build a specification for Hardness, we need to measure the full load curve and use calculations (like the assessment of the meander point) to identify the load. We cannot simply collect a peak value measured up to some deformation point; the deformation when the specimen reaches the Hardness value appears to be both paper and flute structure-dependent.

For testing in CD and MD orientations, A-flute and C-flute curves have the traditional shape with an initial Hardness plateau and a peak value. While the plateau region shrinks as we move to heavier papers, and for C flute it becomes less of a plateau than a change in slope on the curve, we can consistently identify that a Hardness point exists. By contrast, the D-flute materials do not exhibit a Hardness peak distinct from the maximum; these curves have no plateau region. The B-flute structure is intermediate, displaying a clear Hardness value for lightweight papers but not for heavier papers. This shift in the response has implications for correlations between flute structures, as we shall later see.

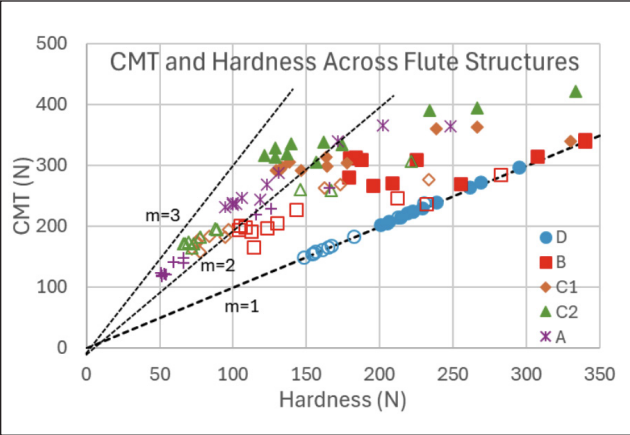
The two C-flute profiles studied differ in flute count, not in flute height. Similarly, the difference between A-flute and C2 is primarily in height and not in pitch. Averaging all six composite load curves for our lightweight papers (Materials 1–6; **Fig. 4**) allows us to examine how these differences in geometry might impact Hardness and CMT on average, independent of furnish or other papermaking variables. The shape of the load curves, and in particular the Hardness and CMT values, appears much more dependent on the height of the profile than the pitch of the flutes, given the similarity between the two C-flute configurations in contrast with that of the A-flute structure. The data likely includes too much inherent variation for us to tease this out



4. Composite load curves of A, C1, and C2 flutes in MD (solid) and CD (dashed) orientations, averaging the six nominal 23-lb mediums (see Table II). The unevenness of the MD curves at and past the peak results from the averaging process across six papers, with differences in the ultimate extent of the load curve captured past the peak value.

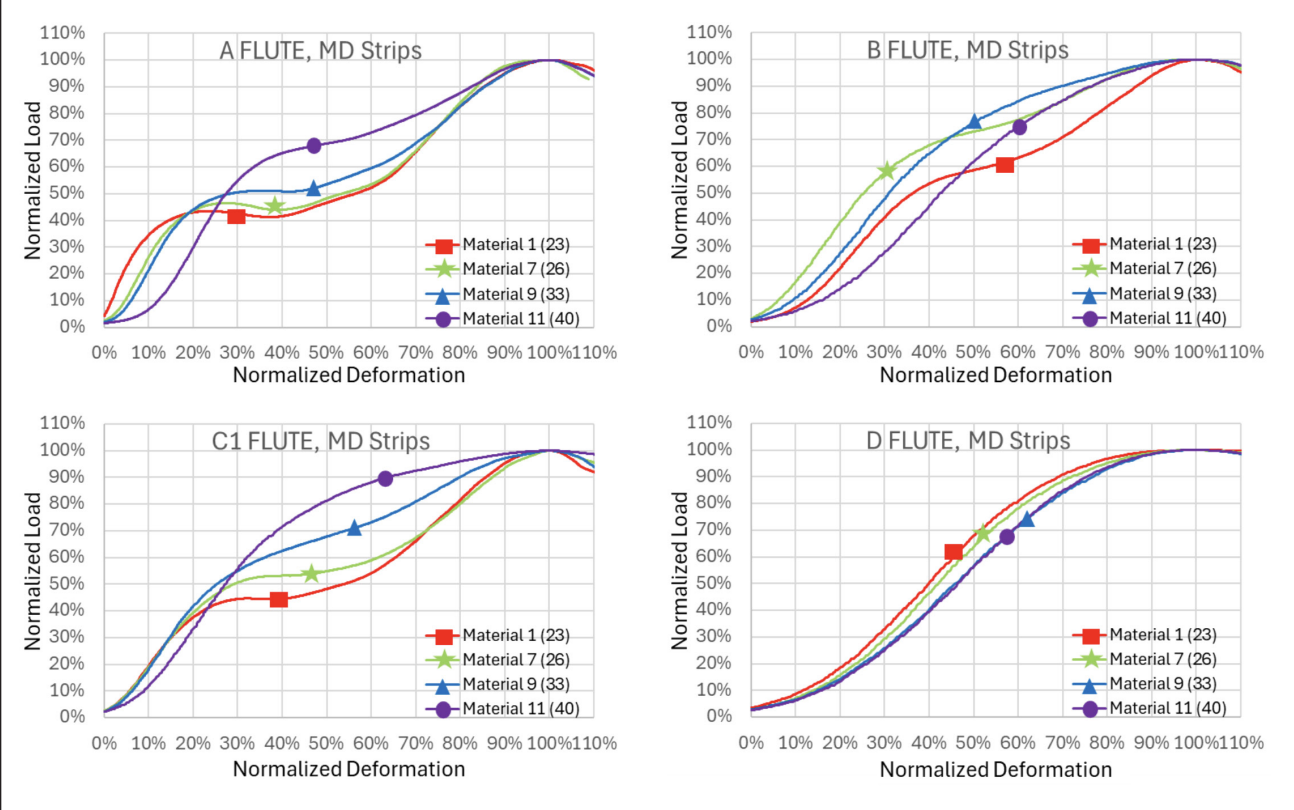
experimentally without a much larger study across a range of more tightly and systematically changing flute structures. The relationship of pitch and flute height to the actual Hardness and CMT values is likely best explored through modeling; e.g., finite element analysis (FEA) [44-48].

Plotting CMT values against Hardness (Fig. 5) hints at differences that occur as a result of shifting flute structures.

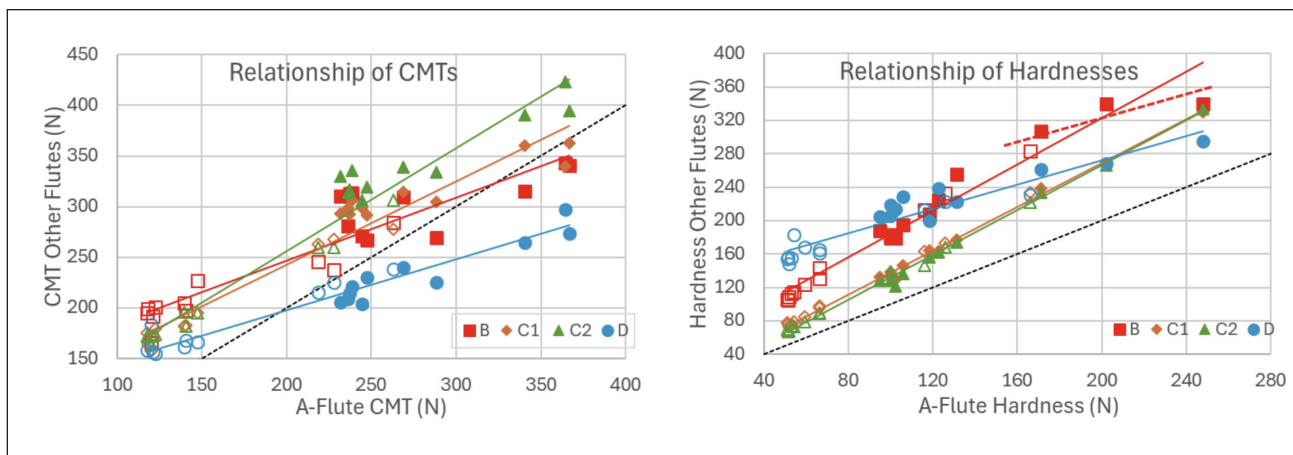


5. The relationship between CMT and Hardness across flute structures for the 11 papers in this study. The MD values are indicated with filled symbols and CD values with open symbols.

For D-Flute where there is only a single peak in the curve, the first peak or inflection point is also the maximum, and thus those values all fall on a straight line with a slope (M) of 1. Heavyweight B-flute samples also fall on that line, whether assessed in MD or CD. Most samples tested in A-flute and C-flute fall in a range where M (CMT/Hardness) is between 2 and 3. But even for those structures, as paper weights (and thus Hardness and CMT) increase, the ratio shifts closer to the $M = 1$ line. With increasing basis weight, CMT plateaus while Hardness keeps increasing. The ratio



6. Load-deformation curves, scaled relative to the deformation and load at the peak (CMT) value, showing both the evolution of the load curve with material and weight and the self-similarity of the loading behavior evolution across weights and flutes.



7. Correlations of CMT and Hardness measured in a range of flute structures with values measured in A-flute for the 11 papers in this study. The MD values are indicated with filled symbols and CD values with open symbols, with the two subsets overlapping. The dashed black line serves as a visual reference with a slope of 1.

remains consistent for the longest when we use A-flute as our testing geometry.

We can normalize the load curves by dividing the load at any point by the peak load (CMT) and the deformation by the deformation at that peak load for each material and flute structure. The resulting curves highlight the similarity in failure mechanics across weights and flute structures (**Fig. 6**). Lightweight material tested with larger flute structures (e.g., Material 1 or 7 in A-flute) exhibits classical loading behavior, with a distinct first peak (Hardness). As paper weight increases or flute size decreases, the proportional deformation point and load for Hardness both increase. The curves are self-similar, with (for example) Material 11 in C1-flute and Material 9 in B-flute reaching very similar normalized load at respective normalized deformations. The relative stiffness of the paper (associated with its basis weight) and the fluted structure (length scale and curvature) appear to both govern both the shape of the curve and M . Effectively, both heavier papers and smaller flutes make the fluted structure more geometrically stiff.

While we consider Hardness to be the first peak or inflection, this analytical perspective would appear to imply that though the peak value (CMT) is conserved across all testing approaches, Hardness itself as the transition from elastic to inelastic failure of the fluted medium may not be. For sufficiently small flute structures (or sufficiently heavy papers), the fluted medium may have no meaningful elastic response and perhaps, as a consequence, no real hardness value.

CMT and hardness correlations between flute structures

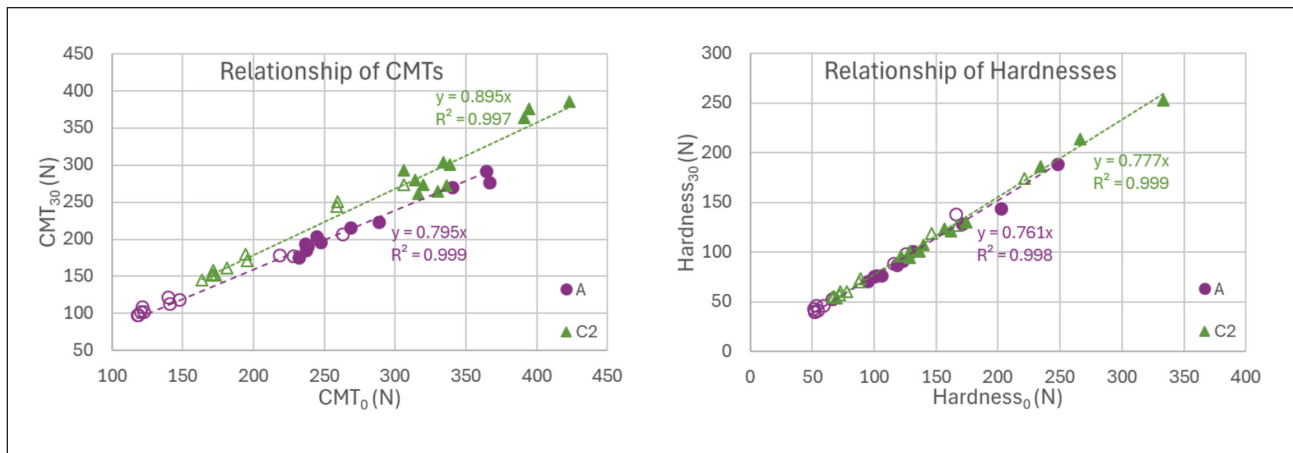
In **Fig. 7**, we display the CMT and Hardness measured for other flute structures against the values measured for A-flute, combining measurements in the MD and CD directions. As paper weight increases, the measurements increase for all flute structures. Because properties can

Flute	CMT	Hardness
B	0.838	0.957
C1	0.934	0.996
C2	0.950	0.996
D	0.936	0.894

IV. Coefficient of determination (R^2) values for the lines of Fig. 7. The correlations are better for Hardness than Concora corrugating medium test (CMT), but reasonably robust in all cases.

appear to correlate due to their mutual correlation with basis weight rather than any inherent/foundational relationship, examining the MD data alone does not necessarily allow us to separate a potential basis weight impact from the physical geometry of the respective tests. However, by including the same weights of papers as measured in the CD, we observe clear trends in the related strengths that are independent of the masses of the papers. The correlations are better (less noisy, higher coefficient of determination [R^2]; **Table IV**) for Hardness (first peak or inflection) than CMT, but reasonably robust in all cases. Interestingly, even for D-flute where there is only a single peak and thus the Hardness and CMT values for those curves are identical (and perhaps there is no physically meaningful Hardness value despite the ability of equipment to “measure” one), the D-flute correlation is strong with both A-flute Hardness and A-flute CMT. The stronger correlation of the single D-flute value with A-flute CMT over A-flute Hardness supports the previously-mentioned hypothesis that the D-flute value is most likely a CMT peak, and that the Hardness value cannot be measured as the geometric stiffness of the fluted structure increases.

The strong correlations across flute types answer the



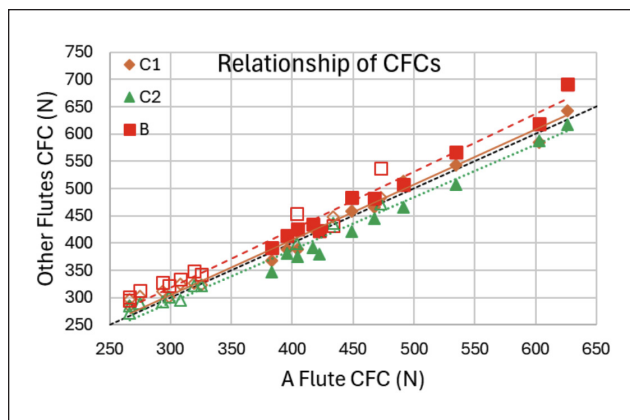
8. Correlations of CMT and Hardness immediately out of the fluter (time 0) and after 30 min of equilibration in the testing atmosphere (time 30) measured for A and C2 flutes for the 11 papers in this study. The MD values are indicated with filled symbols and CD values with open symbols, with the two subsets overlapping (R^2 : coefficient of determination).

basic question of whether there is value in testing CMT in a different geometry; values generated would seem to differ only by a constant factor (the slope of the line of correlation) independent of basis weight or measured value. The correlations between CMT values for different flutes all have different slopes even for the two C-flute structures, implying that the relationship (and essentially, the CMT value) is dependent on the flute count. By contrast, the Hardness relationships are nearly identical for the two C-flute structures and have an offset for the B-flute relationship, though with essentially the same slope. As noted previously, the Hardness disappears in B-flute above a certain load (or perhaps more appropriately, there is no subsequent peak after the initial loading event that we might call Hardness as distinct from CMT), and we see for the B-flute data that the highest points have a relationship similar to the slope for D-flute (dashed line, Fig. 7) where again there is no distinction between the first peak and the maximum measured value. Broader studies across more papers and flute structures are needed to understand this better.

Taking a similar approach to examine CMT_{30} in comparison with CMT_0 , we observe (Fig. 8) strong linear correlations for both Hardness and CMT in the respective flute structures across the basis weight range and independent of direction of sample orientation in the test. For CMT, the slopes are different, while for Hardness the slopes are statistically similar and the populations clearly overlap.

CFC

The CFC results also correlate linearly across flute structures (Fig. 9). The similarity of the best fit lines is to be expected, given that in all cases, we have the same amount of material under test. The slopes of the correlations have overlapping 95% confidence intervals that all include 1 and with R^2 values of 0.985 or higher, implying very limited impact of flute structure on the load the fluted paper can carry, even given the variation in the test. The failure mode



9. Correlations of fluted edge crust tests (CFC) measured in a range of flute structures with values measured in A-flute for the 11 papers in this study. The MD values are indicated with filled symbols and CD values with open symbols, with the two subsets overlapping. The dashed black line serves as a visual reference with a slope of 1.

is apparently similar across flute structures, likely indicating that the curvature of the flute structures studied all inhibit buckling at the specimen length scale and that these papers are all failing in compression during the test [49,50]. It would thus appear that CFC, tested in the lab using either the standard test (A-flute) or any other flute structure examined, should correlate similarly with the CD load carrying capacity of the medium, regardless of the flute structure of the resulting combined board.

Variation

The variation in our results helps us understand these tests and sources of variation in measurement relative to other tests in the industry. The average coefficient of variation (COV; % variation) for the CMT and Hardness values were statistically similar at 4.2% and 4.0%, respectively. This might be considered the best estimate of pure testing variation available given the sourcing of the papers, which as

	CMT COV	Hardness CO	CFC COV
All data	4.2%	4.0%	4.0%
MD specimens	4.6%	4.1%	4.8%
CD specimens	3.9%	4.0%	3.2%
A ₀	3.9%	3.3%	3.2%
B ₀	4.3%	4.4%	3.8%
C ₁₀	4.5%	4.5%	4.3%
C ₂₀	4.7%	4.1%	4.6%
D ₀	4.5%	4.8%	-
A ₃₀	3.6%	3.5%	-
C ₂₋₃₀	4.2%	3.7%	-

V. Coefficients of variation (COVs) for the Concora corrugating medium test (CMT) and fluted edge crush (CFC) test (MD: machine direction; CD: cross-machine direction).

noted previously, took all efforts to reduce material variation. For comparison, the average COV of the S-Test and SCT values on these materials was 10.0% and 5.2%, respectively. For the S-Test, variation was similar to what is observed in other studies [39,40], indicating the primary source of that variation is inherent in the test itself, given the materials studied. The SCT variation was notably lower than typically reported elsewhere, indicating a strong contribution from material variation in the papers being tested in most studies.

Examining the variation in CMT measurement across flute structures and test times (**Table V**), we find the lowest COV for A-flute. Testing after 30 min. of equilibration in the lab also results in more consistent measurements. While for CMT the difference in measurement variation between flute structures is not statistically significant, for both Hardness and CFC, the differences are meaningful. Testing the papers in this study in an A-flute configuration produced more consistent results than testing in other structures.

CONCLUSIONS

The shape of the CMT load curve is a function of the geometry of the fluting profile and the stiffness of the papers, with smaller flutes reaching both the initial peak (Hardness) and their ultimate peak load (CMT) sooner and providing a stiffer structure. The values correlate approximately linearly between flute structures across our paper supply and across testing approaches, though we find flute-dependent slopes and intercepts, as well as evidence of a transition in failure mode as flute size and basis weight change. While B-flute provides consistently higher Hardness values than C-flute, and both are higher than A-flute, for CMT, the slopes and values do not trend consistently with flute structure.

Understanding the underlying mechanics driving changes due to flute structure is likely best studied numerically, informed by experimental data on a range of materials and structures, which can help with optimization on the corrugator. However, our experiments indicate that from a testing methodology perspective, the linear correlations, lower variation of the test when using A-flute, and consistency of the CFC measurement across flute structures all support the ongoing value of the A-flute test method for paper quality control. Whether the Hardness or CMT best relates to the requirements for board and boxes in the field remains open but can now be studied with a narrowed focus across board types and flute structures.

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ABOUT THE AUTHORS

We are presenting the results from an extended study designed to fill in some of the literature gaps identified in our understanding of strength properties associated with corrugating medium, considering the increased interest by the industry in medium performance characterization. This research supports parallel development of specifications and new test approaches for corrugating medium, filling in gaps in the literature.

The most difficult aspect of this study was accurately assessing the performance characteristics of interest. This required verification of prior techniques and some particular equipment.

The differences in relationships of CMT and Hardness across flute structures and basis weights was particularly interesting. Also, the robustness of correlations across flute structures was not expected, and was gratifying to find. It simplifies some of the work in this area moving forward.

As the papermaker has no information available regarding the fluting structure to be created from a given roll of paper, loss of a general test assessing a medium's "fitness for use" would pose a particular



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Searcy

challenge to the quality assurance process. This work validates the current quality metrics.

Some of what we learned would be best validated using computer modeling, which would be valuable. This research also enables an updating of the work of Long and Maltenfort to corrected CMT values with board flat crush performance. It also provides baseline data for additional theoretical work linking paper and board properties with those associated with box performance.

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ABOUT THIS PAPER

Cite this article as:

Frank, B., Hughes, B., Cooper, E., et al., *TAPPI J.* 25(4): 221(2026). <https://doi.org/10.32964/TJ25.4.221>

DOI: <https://doi.org/10.32964/TJ25.4.221>

ISSN: 0734-1415

Publisher: TAPPI Press

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