NEXT GENERATION OF DYNAMIC TESTING DEVICES

JOHN STAPLES AND JASON STEPHENS

NEW TESTING TECHNOLOGY IMPROVES PAPER MILL CORE DESIGN, SELECTION, AND QUALITY BY CONSISTENTLY PREDICTING A CORE'S ABILITY TO SUSTAIN CYCLIC COMPRESSIVE LOADS

THE EVOLUTION TO SUPER-WIDE ROLLS—UP TO 142 inches in length, carrying loads in excess of 16,000 pounds—has placed new demands on cores. The shift from older, double-drum winders to new roll- and core-supported winders has also challenged cores to expanded levels of load-bearing capacity. These and other changes intended to boost productivity and quality in mills and pressrooms present new performance issues that must be addressed by core manufacturers.

To meet these requirements, paper mill cores must have suitable dimensions, adequate tolerances, and sufficient stiffness and strength. Mills typically specify core dimensions, tolerances, and minimum flat crush levels. In some cases, beam stiffness and axial crush minimums are also set. However, the capability to support the weight of jumbo rolls in winders and presses is not necessarily ensured with such specifications or test methods.

Fig. 1. The testing device in operation.

For instance, flat crush, axial strength, and beam stiffness are static tests involving no core rotation. Such tests do not reflect a core's ability to sustain the cyclic compressive loads it is subjected to during winding and unwinding.

So, in the 1980s, scientists from the United States and Europe set out to fully understand why compressive loads cause core failure and how to design in core properties that withstand dynamic load fatigue. This understanding culminated in the development of a device that recorded a core's dynamic load-bearing capability and there are several commercial devices on the market today (more about this later).

Next, the science of Finite Element Analysis (FEA) technology was combined with field trial data to validate the accuracy of this early model-testing device. FEA is the same technology used to design in performance attributes of aircraft wings and high performance automobiles. FEA models a structure (in this case spiral wound paper cores) to describe how each finite section of the structure behaves under stresses or loads. The field trial measurements included data from strain gauges, load transducers, and pressure sensitive film that recorded actual load patterns produced by winder chucks.

As a result, Sonoco, a leading tube manufacturer, developed and patented an improved test device, which consistently and accurately measures a core's ability to sustain cyclic compressive loads or dynamic load.

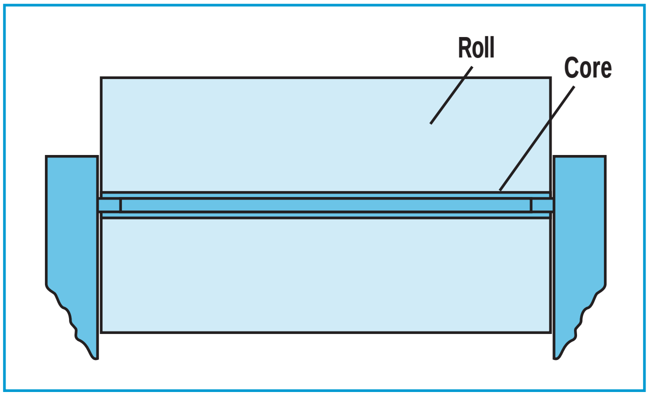

Fig. 2. Roll weight is transmitted across the core to the winder mandrels or printing unwind stand chucks.

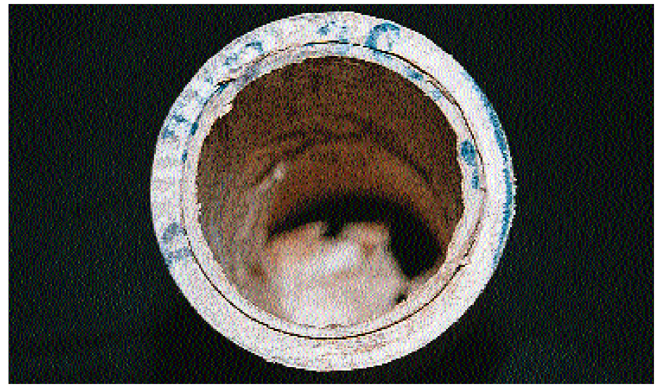

Fig. 3. Example of a damaged core, which was unable to sustain its load.

This next generation test device is called the Sonoco Dynamic Strength (SDS™) tester. Duplicating the stresses induced in paper mill cores supporting jumbo paper rolls in winders and presses, the test can be used to determine the proper paper mill core for any application and for quality assurance testing.

DESCRIPTION OF THE SDS™ TEST

The test involves using a fiber-reinforced rubber belt to apply a load on a rotating core **(Fig. 1)**. Core loading is developed by displacing the lower belt pulley relative to the chucked test specimen. Load is steadily increased until core failure occurs. The test result is the load level when the core fails.

Although conceptually simple, the test device is both robust and sophisticated. The expandable chucks are precision built and controlled so that cores are gripped uniformly and consistently. These chucks can accommodate typical variations in nominal core inner diameters, and both 3- and 6-inch cores (76.5 and 150.4 mm) can be tested.

To help ensure load levels are applied uniformly across the test specimen, the chuck and belt pulley shafts are closely aligned. Also, the test frame is massive relative to the load levels required to fail even the strongest cores. Essentially no structural distortion is ever incurred. This also is needed so loads can be applied uniformly to the core. Cores are loaded directly by the belt in the test, i.e., the core is not mounted in a hard ring or sleeve as in all other known dynamic strength testers [1, 2]. Thus, no detrimental core compression from core/sleeve interference is incurred.

Load level, load application rate, and rotational speed are all electronically controlled and each is independently monitored. These measures ensure loads are applied consistently from one test to the next. Furthermore, the load level and load rate accommodates cores of all strengths. No fiber core is too strong for the test and none should be so weak as to fail under the initial load. All levels are automatically set which leaves little possibility for operator error. These features and precautions make the test both accurate and repeatable.

THE NEED FOR SDS™ TESTING

A primary function of paper mill cores is to support most or all the weight of rolls during winding and unwinding. This weight is transmitted across the core to the winder mandrels or printing unwind stand chucks (**Fig. 2**). Thus, the core wall is cyclically compressed between the paper and mandrel (or chucks) with each roll revolution. During winding, this compressive loading becomes more and more severe as the roll reaches its maximum size. Eventually, the resulting localized core stresses may be large enough to fail improperly chosen or poorly made cores. Such failures initiate as a crack at or near either core end. Because the roll is rotating, this crack soon propagates into a complete circle (**Fig. 3**). When this happens, the core is no longer functional and the roll is unusable and must be salvaged in a secondary winding process. This slows production and requires additional equipment and personnel [3].

As is described later in the paper, the test can predict a paper mill core's ability to sustain the repeated cyclical compression loading of winding and unwinding. Thus, testing helps eliminate time consuming and costly salvage operations.

Our research shows that other available dynamic strength test devices [2, 3] have short comings, despite their conceptual similarity with the SDS™—test (**Fig. 4**), and do not reliably predict field performance. One concern is the use of a ring or sleeve on the outer diameter of the core specimen (Fig. 4), ostensibly to simulate the stiffness of the wound paper. Used on other testers, sleeves can influence test results by creating false load values, caused by inconsistent core to sleeve fit. In practice, a degree of mismatch always exists between core outer diameter and sleeve inner diameter. This mismatch superimposes a varying degree of compression on the core during the test. Our research has shown that this

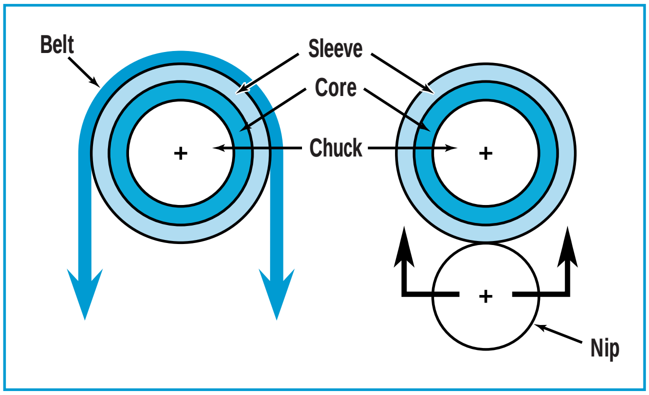

Fig. 4. Conceptual depiction of other dynamic load tests - note the hard sleeves placed on the core outer diamer.

compression alters test results, with high compression yielding fictitious, high dynamic strength values. Moreover, the amount of compression is determined by the technician who selects the "proper" sleeve size.

Our research also indicates that excessive chuck expansion can fail cores before core rotation even begins. It is evident that significant pre-loading is caused by the chucks. The same test also requires radically different loading profiles to test low and high strength cores. Results obtained from these two load settings are not a valid basis for assessing the relative roll weight capacity of different core designs.

In fact, Sonoco held the patent on a first generation dynamic load or cleavage test still in use today. These patents were allowed to lapse after realizing quite a different tester was essential to accurately measure dynamic load. So while other testers record the sustainability of cyclic compressive loads, they do not accurately and uniformly repeat results. This limits their ability to predict core performance in the field.

The SDS™ test alleviates these difficulties by elimination of sleeves, improved chuck design, and use of a single loading profile for all core types. As discussed later, measured core strength correlates strongly with core roll weight capacity as measured in the field. This correlation has never been demonstrated using any of the alternative dynamic strength testers

QUALITY ASSURANCE

The test is also very useful for quality assurance testing of paper mill cores, which must support heavy rolls. This is very important since unstuck plies and other tube defects are known to contribute to paper mill core field failures. The sensitivity of the test to such defects has been proven in many instances. In designed experiments, test results of cores with intentionally added defects had reduced performance. Furthermore, the reduction in dynamic strength performance was directly related to the severity of the embedded defect. Also, since its development, the test device has been utilized to monitor core quality at several Sonoco manufacturing locations worldwide. The collective experience shows that quality defects incurred during manufacturing will be discerned with testing.

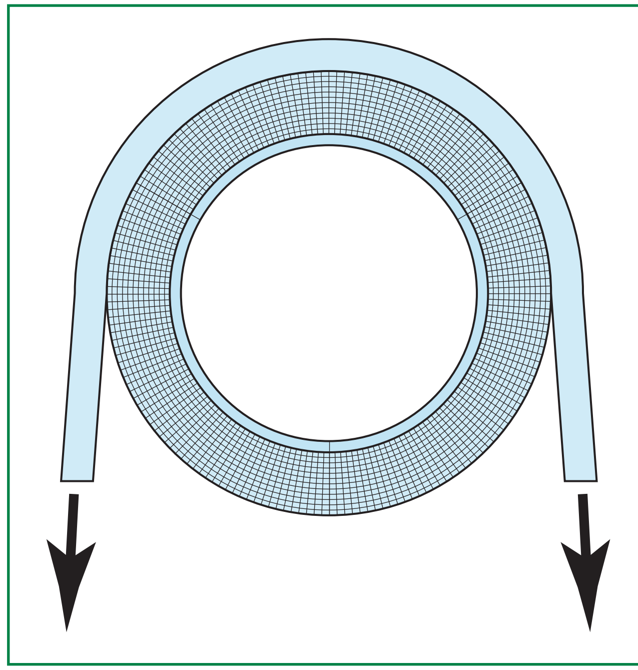

Fig. 5. Finite element model of core under SDS™ test loading.

VERIFICATION OF THE TEST

One may question whether a test, which transmits loads with a belt wrapped around the top half of a test specimen, is indicative of actual field performance. However, core stresses induced in the SDS™ test are equivalent to those induced in cores supporting jumbo paper rolls in winders and pressrooms. Furthermore, the test is predictive of roll weight capacity. These claims are supported by the following results.

Stress Analysis

The advent of increasingly powerful computers has enabled stress analyses of very large and complicated structures. The most prevalent technique utilized in such stress analyses is the finite element method, as summarized earlier. Following is a more detailed description of this scientific method.

The finite element method (FEM) is a powerful numerical procedure which enables estimation of stresses in structures. Even so, many assumptions and simplifications are required of an analyst conducting a finite element analysis (FEA). For example, structure geometry must be approximated by a "mesh" comprised of simple polygons and tetrahedrons, etc. Likewise, the properties of the material(s) comprising the structure must be known and numerically approximated. The analyst must also mathematically specify how the structure under study is mounted and loaded. These and other

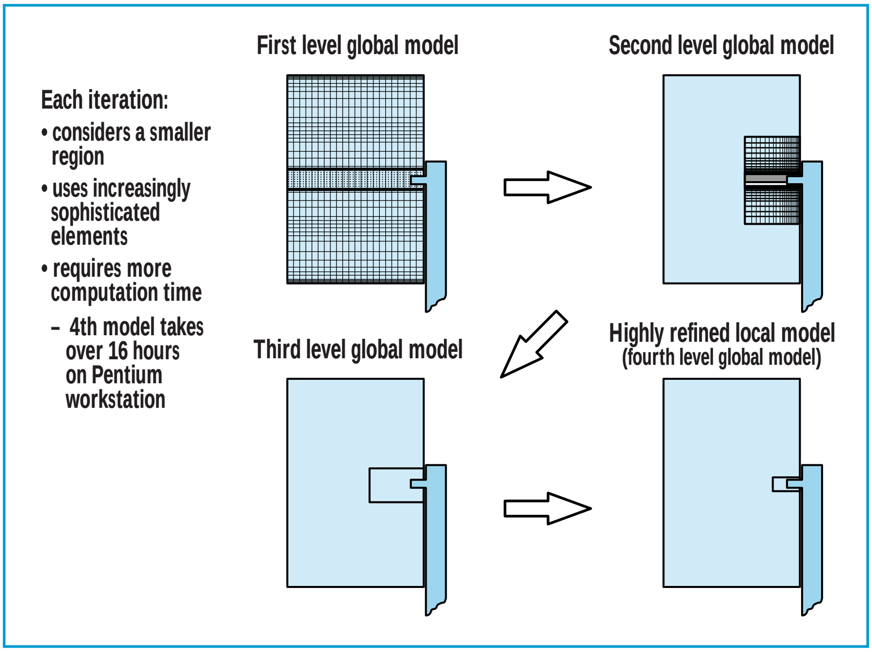

Fig. 6. Procedure used to insure good accuracy of predicted stress levels of cores supporting jumbo paper rolls.

Sonoco researchers have recently analyzed stresses in cores supporting jumbo paper rolls. This required advanced computer technology, state-of-the-art finite element software, and sophisticated modeling techniques.

The modeling procedure warrants additional description. As illustrated in **Fig. 6**, four separate models were needed for each analysis. This is because stresses and strains change drastically in the vicinity of the chucks. The finite element method requires a very large number of equations (or elements) to accurately estimate stresses and strains in regions with such gradients. Furthermore, determining the contact state between the core and chuck and between the paper and core required a time-consuming iterative process. It was performed computationally to accommodate these features in a model which also included elements to simulate the rest of the jumbo roll. The solution was to build several models. The first model included enough elements to simulate one half of the entire structure. Displacements obtained from this run were utilized to specify the boundary conditions of a second model. This model, of a smaller portion of the roll, contained more elements in the region of the core chucks and utilized a larger number of contact elements. This process was repeated twice more. Each subsequent computer run yielded more accurate details regarding the core stress state in the vicinity of the chucks. In this way, good numerical accuracy in predicted core stresses was achieved.

Stress distributions determined for cores under test loading and for those in cores supporting jumbo paper rolls were very similar. Thus, cores which rank higher in the test should also be able to sustain higher roll weights (and vice versa). This expectation has been confirmed with mill winding tests.

assumptions dramatically influence results of all finite element analyses. Thus, it is imperative that test results are available to confirm the validity of the resulting finite element model.

Such test results have been obtained for cores under SDS™ test loading and for cores supporting jumbo rolls in winders. These results validate both finite element models. Thus, the predicted stress states are in themselves directionally correct and their close similarity is credible evidence that the test realistically simulates conditions in cores supporting jumbo rolls.

The SDS™ Test FE Model

The FEA model of a core in the SDS test is shown in **Fig. 5.** This model was created using EMRCNISA, a commercial finite element code. The model accounts for both frictional slip between the belt and the core outer diameter, and compression loading of the core inner diameter by the chuck.

Validation of the model involved testing of many core designs. Core designs which the model predicted would have increased stress levels tested lower and vice versa. Other systematic but proprietary validations were also successfully conducted. These results enabled clear identification of the stresses which govern test performance.

Stresses in Cores Supporting Jumbo Paper Rolls

Many researchers have realized that stresses in paper mill cores supporting jumbo paper rolls are the combined resultant of two separate loads [e.g., 4 - 6]. These are the stresses due to winding and the weight load described previously. However, the computational ability required to accurately estimate resultant stresses was too costly or non-existent.

Field Trials

The close agreement found between stresses induced in the test and in cores supporting jumbo paper rolls suggests test results are indicative of roll weight capacity. This was experimentally confirmed with extensive field tests [3, 7]. In these tests, paper was wound on cores until they failed. Failures were immediately detected using special electronics. Roll weights at failure were compared with SDS™ strength of samples taken from the same parent tubes (**Fig. 7**). These results confirm that results are indicative of roll weight capacity. Fur-

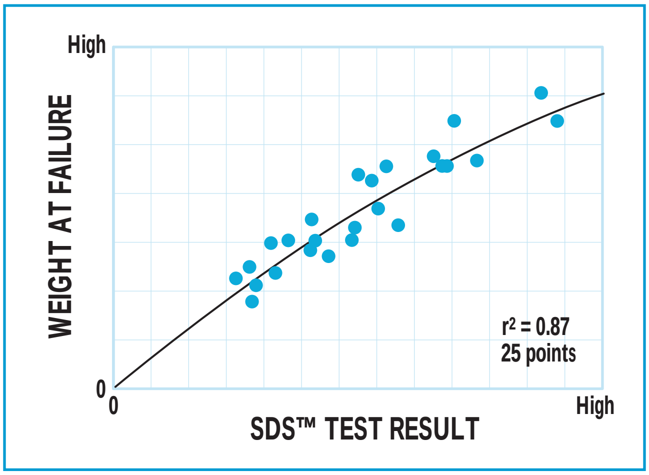

Fig. 7. Paper mill core failure weights compared with test results.

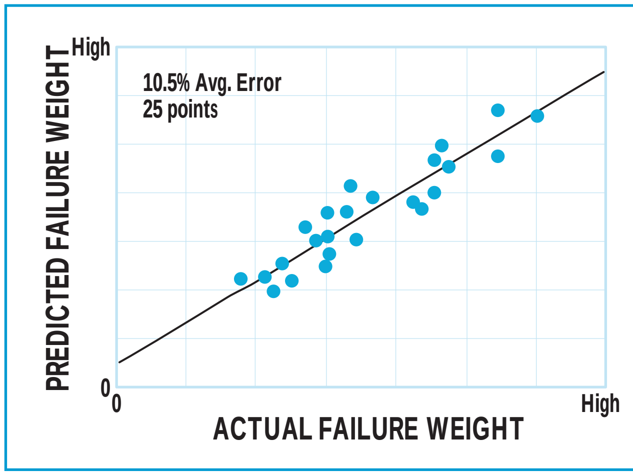

Fig. 8. Comparison of actual failure weights to predictions based on SDS™ test results.

thermore, roll weight capacity can be predicted from test results using experiment-based correlation. This is evident in **Fig. 8**. The average error in roll weight capacity predictions based on SDS™ results was just 10%. Such field confirmation has not yet been published for core strength measured with other dynamic strength testers.

THE FUTURE OF TESTING

In late 1998, Sonoco's tester will be available to the industry through Trace Laboratories, an independent test laboratory located in Palatine, Ill. This agreement allows mill and press room personnel, as well as other tube manufacturers, to have equal access to this device. Potential benefits include reduction of excessive safety margins in paper mill core designs and fewer failures due to poor core quality.

John Staples is employed by General Electric (formerly a research engineer with Sonoco) and Jason Stephens is a mechanical engineer with Sonoco in Hartsville, SC.

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