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Individual Test Rig for Measuring the Creep Behaviour of Corrugated Board for Packaging

V. Köstner[1], JB. Ressel[2], B. Sadlowsky[1], P. Böröcz[3]

[1]Institute for BFSV
Ulmenliet 20, 21033 Hamburg, Germany
Phone: +49 40 42875-6046

[2]University of Hamburg, Department of Wood Science
Mittelweg 177, 20148 Hamburg, Germany
Phone: +49 40 42838-0

[3]Széchenyi István University, Department of Logistics and Forwarding
Egyetem tér 1, 9026 Győr, Hungary
Phone: +36 96 503-400
e-mail: boroczp@sze.hu

Abstract: Corrugated board is one of the most important and most popular packaging materials worldwide for transporting goods. Due to its hygroscopic behavior, it has a tendency to creep when subjected to stress under a constant load, which can ultimately result in loss of strength, with possible damage to products. The creep behavior of corrugated board is still a largely under-researched area. This paper attempts to examine the long-term behavior of corrugated board during use more precisely than before, and presents the first step and results of the research process. For the measurement, a compact and high-precision individual test rig was developed and used, in order to reduce the side effect of coupled systems, that is, to avoid their mutual influence. This paper successfully presents results reproducible with the described test rig apparatus for determining the creep behavior of corrugated board. It will be continued to publish further results of the research in the near future.

Keywords: corrugated board, creep behaviour, packaging material

1. Introduction

For the EU-28, in 2013, 40 % of main packaging materials were paper-based packaging, including corrugated board as the most popular and well-known transport packaging [1]. Thanks to the special construction of corrugated board relatively high strength features can be achieved, coupled with low weight. The only Achilles tendon or disadvantage of corrugated board is its hygroscopic behavior. If corrugated board packaging encounter with high relative humidity (RH), it loses up to 50 % of its strength [2-5].

Various international standards (FEFCO, ISO, ASTM, TAPPI) use testing practices to measure the mechanical characteristics of paperboard, but these are mostly limited to short-term measurements aimed at assessing compression strength [6-9]. Historically, the corrugated board industry has established the nature and scope of compression strength measurements. Experts and researchers believe that measurement results derived from box compression test (BCT) allow them to evaluate the compressive behavior of boxes. However, it needs to be noted here that compression strength measurements were developed primarily for quality control purposes. Furthermore, large production volumes do not allow any of the test methods to be applied for a relatively long duration.

The current standards and guidelines do not include a quality standard that would take this type of long-term load into account. Furthermore, it is difficult to give an appropriate estimate of the ability of corrugated board to cope with in-transit stress. In practice, therefore, safety factors are used to take stresses such as high RH and transport loads into account. This can lead to significant overpacking, and consequently a waste of resources. However, if the product-package system is under designed, that can result in packaging failure with a possible risk of product damage [10-11]. T. Trost and J. Alfthan published in 2016 the current state of the scientific knowledge about the standards for optimizing corrugated board packaging for exporting industry. There they illustrate the lack of information in the areas of the effects of creep and varying climate conditions [12].

Although previous studies have been done on the mechanical behaviors of these packaging structures under static compression [13-16], they mainly focused on the mechanical behaviors of a corrugated board box itself. Other papers presented results and brief reviews of designing and modeling the stackability of cardboard boxes using a finite element method (FEM) [17-18]. The results of these tests can be applied as input data for decision support models and processes aimed at selecting the right protective packaging system [19]. However, it is well known that the long-term distribution environment and storage can affect the real strength of packaging, especially in the case of corrugated paper packaging [20].

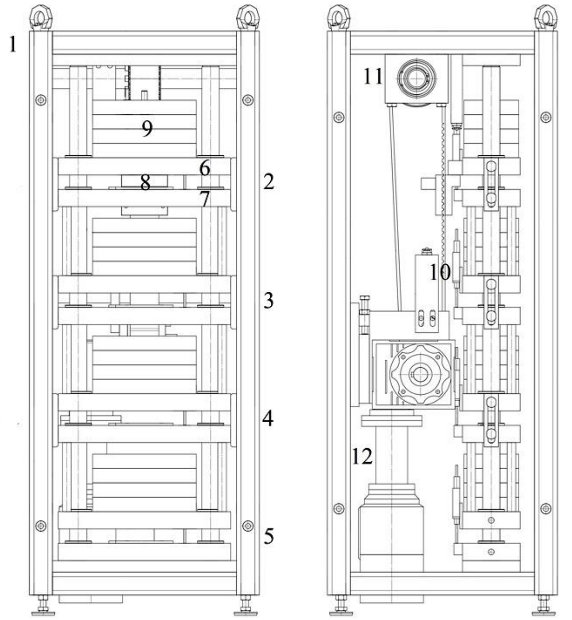
The aim of this paper is to develop a new test rig for the examination of creep behavior of corrugated board on edge crush test (ECT) specimens for laboratory use to better exploit the material's potential. The long-term strategy of the experimental research is to create a guideline for packaging producers and engineers of corrugated board, firstly to prevent overdesigning and secondly to avoid product damage due to failure of the paperboard packaging.

2. Background and Methods

In 1963, McKee established a connection between the ECT value, bending stiffness (BS) and BCT value of corrugated board [21]. The result of this research led to the McKee formula. Recently, this formula is widely used to calculate the BCT value of packaging made of single-walled corrugated board from its ECT value and BS [21-23]. Based on the assumptions of McKee, research into a possible correlation between long-term ECT and long-term BCT values was carried out at the Institute for BFSV at the Hamburg University of Applied Sciences.

As a result of the research project, called “Development of Test Standards relating to the creep Behavior of heavy-duty Corrugated Board for determining the Performance of Boxes manufactured therefrom” (DLR project no. 01FS10018), a creep test rig was designed to determine creep rates in specimens for edge crush resistance (ECT specimen: 25x100 mm). Figure 1 shows the schematic representation of the creep test rig with dimensions of 1060x400x400 mm.

To observe the edge crush resistance and creep behavior of corrugated board the test rig was designed with full consideration of the requirements of ISO standards such as ISO 3037:2013 and ISO 204:2009. These standards specify methods for uninterrupted and interrupted creep tests of metallic materials and the unwaxed edge method for determining the edgewise crush resistance of corrugated board. The basic frame 1 includes four test units 2-5, for simultaneously testing four ECT specimens; this can be seen in Figure 1. The test unit consists of a mounting plate 6 and a specimen plate 7. The test specimens 8 sit on the specimen plates during testing. The weights 9 required for the test are arranged on the mounting plates. Digital measuring sensors 10 are mounted on each test unit for measuring displacement. The lift station 11 and the motor 12 move the test units up and down.



1) basic frame
2-5) test units
6) mounting plate
7) specimen plate
8) specimen
9) weights
10) measuring sensor
11) lift station
12) motos

Figure 1. Stacked test rig

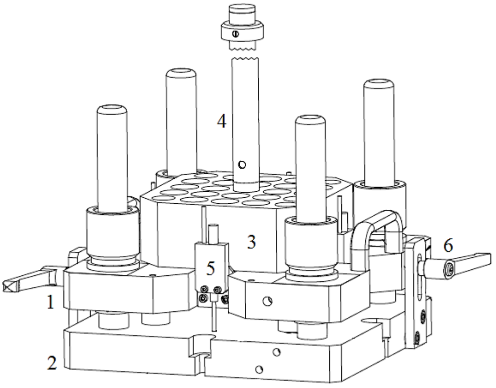
Advantages and disadvantages became clear when using the test rig. The cascade-like construction of the test rig makes it possible to test four specimens at a time. However, due to the combined weights of individual test units it is seldom possible to use the first and fourth level. The construction and size of the test unit severely restrict the dimension of test specimen. In addition, no more than two displacement transducers can be attached per test level. It is also impossible to rule out an influence exerted by the failure of a specimen and transmission of any vibrations associated with this to the other specimens.

3. Requirements of a new test rig

When developing the individual test rig for laboratory use, two areas should be concentrated on: the construction of the test rig and its operating principle. The aim of this research is to ensure the accuracy and reproducibility of the test. The individual test rig has been designed for laboratory use. Small dimensions and a low net weight are essential for ensuring that the rig can be handled manually by one person. At the same time, it is necessary to adhere to the required load range: the minimum load on the specimen is 10 kg, and the maximum is 120 kg. The individual test rig must enable highly accurate measurements. Due to its construction and the high positioning accuracy required the test rig must be designed in such a way that the specimen is loaded in parallel. It is essential that the weights be mounted on the individual test rig rigidly and without any play to prevent uneven loading.

3.1. Individual test rig

Figure 2 illustrates the schematic representation of the individual test rig, without additional weights. The weight and dimensions of the individual test rig are 40 kg and 315x315x680 mm. The test setup essentially consists of two plates precisely parallel in their planes, which can be moved toward each other by means of four guide columns. The four guide columns, which are supported on linear ball bushing bearings, allow the weights to be mounted rigidly and without play. They also ensure the parallel loading of the specimen.



1) *mounting plates*
2) *base plate*
3) *adapter plate*
4) *column*
5) *measuring sensor*
6) *clamping lever*

Figure 2. Individual test rig

When starting the test, the upper plates, known as the mounting plates 1, are raised and fixed in place by means of the corresponding clamping lever 6. The ECT specimen is placed centrally in the test chamber between the base plate 2 and the mounting plate. After carefully releasing the clamping lever, the mounting plate is slowly lowered onto the specimen. The weights can be mounted on the adapter plate 3 via a column 4. The special setup ensures the safe and stable placement of the weights. Digital measuring sensors 5 are mounted on all four sides of the test rig to record the changes in distance during the measurement. All parts of the individual test rig are made of stainless steel to prevent corrosion.

3.2. Commissioning

Commissioning of the individual test rig involves the following three areas:

- Measurement of parallelism,
- Determination of the dead load,
- Comparative tests.

The parallelism of the test plates is of extreme importance for accurately measuring creep rates in ECT specimens. It is essential to check parallelism, especially when the aim is to develop a new test method for generating comparable and reproducible creep rates in ECT specimens. Gauge blocks were used to determine the parallelism of the test plates at eight measuring points. The results of the parallelism measurement showed that the displacement on all points is 20.01 millimeters. Thus, there is no difference in the parallelism of the test plates.

Determining the dead load of the specimen is essential for designing the test loads correctly. In this case, a previously calibrated load cell was placed between the two test plates. The load cell then recorded the arising load. The result of the measurement revealed that the dead load of the specimen was 20 kg; twice the required minimum load of 10 kg.

4. Tests and results

Comparative tests were conducted to assess the accuracy of the test rig. Creep tests were performed on ECT specimens using both test rigs. The subject of the observation was wet-strength, triple-wall corrugated board (DIN 55468-1:2015-06 2.96 heavy-duty board). The examinations were carried out in a climate chamber, simulating an eight-hour cyclical climate with a constant temperature of 23±2 °C and RH rise and fall cycle stages to 50±5 and 90±5 % every three hours (Figure 3 blue graph). Figure 3 illustrates the result of a creep measurement of the individual test rig. The long-term ECT values diagrammed as a function of time and the creep deformation rate.

The red graph forms the creep deformation of the sample. Due to the superposition of the swelling behavior and the creep caused by the pressure load, creep deformation increases in the drying phase and decreases in the penetration phase [24]. The mean creep rate (0.006 mm/h) represents creep deformation (height reduction) as a function of time in the secondary phase of the creep process. At the time of its failure (134 h), the specimen suffered a significant loss of strength and practically collapsed. The criterion for specimen failure was a height reduction of more than 0.5 mm in 30 seconds. The experimental results of all measurements are shown in Figure 4.

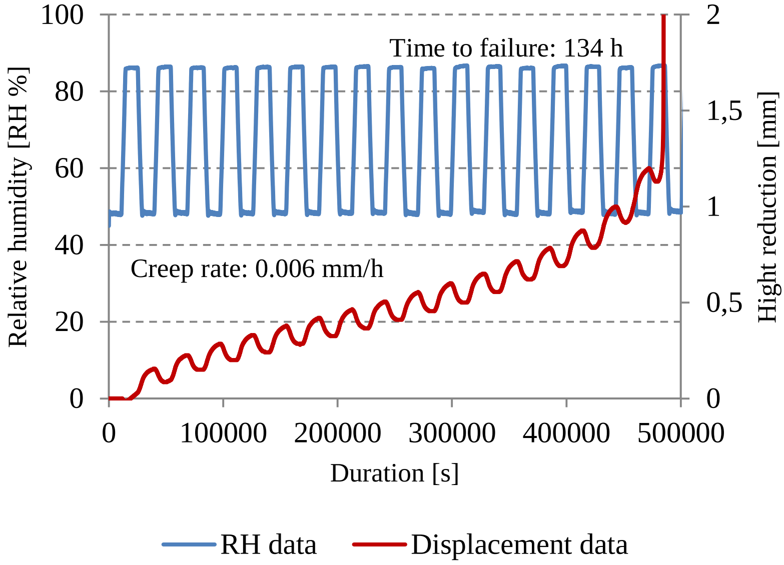


Figure 3. ECT long-term measurement tested with the individual frame

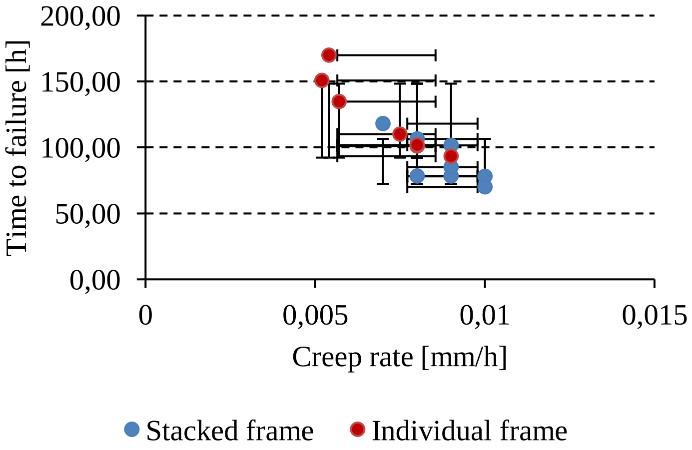


Figure 4. Results of the comparative measurements

Observing the results, it is noticeable that the creep rates and lifetimes generated by the two test rigs differ, considering the variances of the results. Although the average creep rates of both test rigs - stacked frame 0.0088 ± 0.001 mm/h; individual frame 0.0071 ± 0.0014 - seem to be similar, the deviation between the time to failure results of both test rigs - stacked frame 89.5 ± 17.04 h; individual frame 120.3 ± 28.05 h - is significant high. To what extent the deviation can follow from the natural fluctuation of the properties of corrugated board is currently unknown. Additionally, due to the novelty of the measurement it is not possible to assess measurement errors based on the new type of measurement method for creep rates on ECT specimens. Further tests are intended to examine the extent to which external factors influence the values measured.

Considering the results of both test rigs together despite the deviation a linear relationship between the creep rate and the time to failure can be established (Figure 5). The coefficient of determination confirms the assumption. The higher the creep rate, the lower the time to failure.

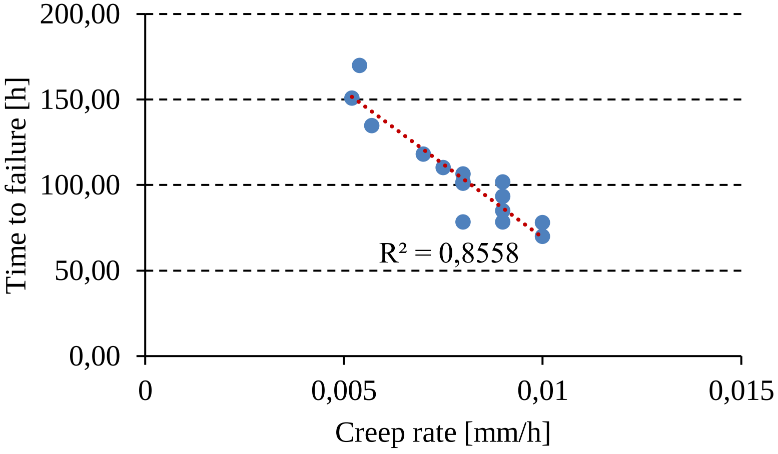


Figure 5. Results of both test rigs

5. Limitations

The individual test rig enables the examination of creep rates in ECT specimens in laboratories and can be controlled by one person due to its compact design and simple handling and operation. The special setup enables the examination of specimens of different heights and geometries. A disadvantage, however, is that due to the superstructures the minimum load on the specimen is 20 kg. Also, only one specimen can be tested at a time. The digital measuring sensor enables the recording of measured values up to 5 µm. The creep rate was unknown when the test rig was designed. While a creep rate of 8 µm can be mapped with the digital measuring sensor, it is not possible to assess the measurement error which may arise thus. In further tests, it will be necessary to examine the measurement error and the possible impact of external factors on the result. Readers of this paper, therefore, are advised to exercise caution when making direct comparisons with results from other research.

6. Conclusion and outlook

Based on the results of this study the following conclusions can be drawn. Using the newly developed, high-precision individual test rig reproducible results can be obtained. Comparison with the stacked test rig gave different creep rates and lifetimes, considering the variances of the results. This variance should be investigated in more detail during further tests. In addition, as a next step, our research will focus on those factors, which can directly influence the measurement.

A new research project deals with the calculation of climate-dependent creep behavior with speed-dependent short-term tests. Thereby, various long-term tests concerning the BCT, BS and ECT will be performed. The results will be transmitted to a computer-aided calculation model under finite elements method (FEM). Subsequently the results of the FEM will be verified by short- and long-term test. Finally, it should become possible to use time- and money-saving short-term tests to estimate the long-term behavior of corrugated board. Hence, in the future, we might be able to utilize the potential of this packaging material better, prevent transport damage and protect the environment.

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