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Research paper

On the determination of transverse shear properties of paper using the short span compression test

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ABSTRACT

The present paper explores the short span compression tester (SCT) as a means to experimentally determine the transverse shear moduli of paper. These moduli, which are known to be difficult to determine by any other means, are of importance for the behavior of paper during tissue manufacturing and in the converting and embossing of paperboard. Testing was conducted on paper of two different grammages both in MD and in CD. By applying the Timoshenko–Engesser theory for buckling of shear compliant materials, estimates of the transverse shear moduli were obtained through the measured SCT values and standard measurements of the Young's modulus and the thickness. These estimates were evaluated by detailed FE-analyses of the SCT setup incorporating initial geometrical imperfections representative for real test conditions. It was found that the Timoshenko–Engesser theory gives estimates of the transverse shear moduli that are within an accuracy well applicable for most engineering purposes. The results suggest that the method is at least as accurate as any other, more involved, method that could be used for the purpose.

1. Introduction

The Short span Compression Test (SCT) was originally developed to measure the compressive strength of paperboard and corrugated board intended to be used as packaging material. For SCT testing of paperboard, a specimen of the paper material is clamped between two clamps a distance 0.7 mm apart. Subsequently a compressive force is applied and the maximum force required to inflict collapse of the specimen is measured. The SCT value is defined as this force divided by the width of the specimen (15 mm according to the standard). As most paperboards are at least 0.3 mm thick the property that is measured is essentially the ability of the material to withstand crushing. For modern multiply paperboards the collapse mechanism is more complex and involves shearing, delamination of the plies and ply buckling, cf. Hagman et al. (2013) and Hagman and Nygårds (2016).

The SCT test has not received much attention when it comes to lighter paper qualities, mainly because compressive strength has not been an issue for the final product, but also because of the fact that the SCT-value for thin paper qualities does not represent the same measure of strength as derived for thicker paper grades following the standard. For thin paper grades the SCT-test rather measures the capacity to resist buckling. In the manufacturing of tissue paper, however, one of the most critical steps is the creping of the paper at the dry end of the Yankee cylinder. It is the creping that provides the tissue paper with its specific properties such as softness, bulk and absorbency (Kuo and Cheng, 2000). During creping the paper material hits a creping blade which assists the release of the paper from the Yankee cylinder surface. Prior to this action, the paper is retained on the Yankee cylinder surface by the use of certain adhesive coating chemicals that are sprayed onto the cylinder surface at the wet end of the Yankee drier. According to current knowledge (Ramasubramanian et al., 2011), the release mechanism consists of the combined effect of breaking the adhesive layer between the paper and the Yankee surface, and the subsequent buckling of the paper web. Hence, any attempt to model the process would require reasonably good estimates of both the peel strength and the paper properties governing the buckling phenomenon. A paper that has been creped in a recently developed creping simulator by Hämäläinen et al. (2016) can be seen in Fig. 1a and b, showing one wavelength of the creped paper.

It should be kept in mind that the paper is strongly anisotropic, especially regarding the relation between the in-plane and the transverse properties. Of particular importance to the creping pro-

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a)
b)

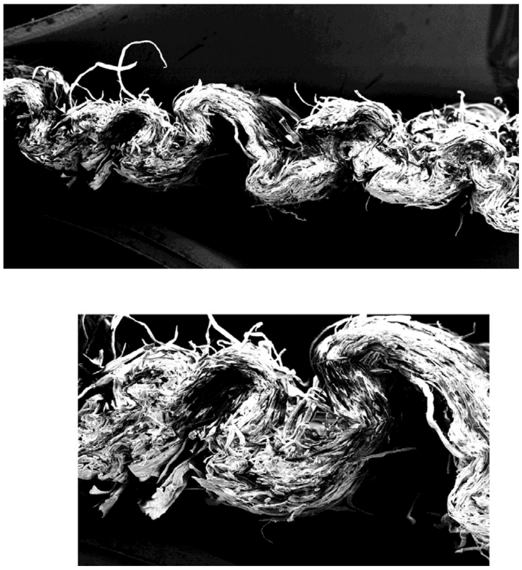

Fig. 1. SEM pictures of creped paper a) overview b) close up of one crepe wave.

cess are the properties in the plane defined by the Machine Direction (MD) and the transverse (ZD) direction of the paper. The properties associated with the Cross machine Direction (CD) are regarded to be of less importance in this context, since the deformation during creping predominantly occurs in the MD-ZD plane. Due to the preferred alignment of the fibers in the MD, this direction has the largest elastic modulus, while the transverse moduli typically are in the order of 0.01 of this value (Stenberg, 2002). Due to this fact, along with the rather short buckling wavelengths involved, it is understood that neither the SCT test nor the creping event could be regarded as a pure Euler buckling phenomenon. Also, the SEM pictures of the creped paper in Fig. 1 confirms that the deformation to a large extent is governed by shear. This may be deduced by the numerous interior delaminations that can be seen inside of the creped paper. Similar damage has been observed e.g. at folding of paperboard that has previously been subjected to shear deformation by creasing, see Dunn (2000). Hence, in order to analyze the creping event the effect from transverse shear cannot be neglected and an accurate determination of the transverse shear modulus is necessary.

Other applications where the transverse shear moduli of paper materials are of importance involve operations like creasing, folding and embossing of paperboard (cf. Beex and Peerlings, 2009 and Huang et al., 2014). Since most paperboards are built up out of several plies, where each thin ply has its unique properties, a complete mechanical characterization requires that the plies are separated and tested individually. The separation of the plies could be done by grinding or by using certain splitting techniques, but the problem remains to determine the transverse properties through testing of the thin plies. This is clearly much more difficult than to determine the aggregate elastic properties of the whole thick paperboard, which may be adequate for applications other than those mentioned above.

Unfortunately, the experimental determination of the transverse shear moduli of paper materials is a rather delicate task. Stenberg et al. (2001) adopted the so called Arcan testing device to measure the transverse properties of paperboard under combined tension and shear loading. One of the potential problems with the method is the uncertainty related to the thickness of the paper, and the penetration of the glue used to attach the paperboard to the loading frame into the paper. Additionally, a very accurate measurement device is needed to capture the relative displacement between the narrow loading frames. Simpler experimental setups for shear testing of paperboard were developed and used by Byrd et al. (1975) and Fellers (1977), where the main difference between the devices is the way they are mounted in the testing machine. The latter of these devices was used for shear testing of paperboard by Nygårds et al. (2007) and Nygårds (2008). However the issues related to the gluing of the specimen and the precision of the strain measurement for these setups are essentially the same as for the Arcan device. While these methods, if care is taken to deal with the issues mentioned above, may work for thick paper qualities like paperboard, they are not suitable for paper materials with a thickness of 0.1 mm or less. The influence from the gluing and measurement errors will then simply be too large to obtain an accurate result. Yet another way of measuring the elastic properties is to use ultrasonic wave propagation techniques. This method was used by Waterhouse (1991) to measure the elastic moduli of paperboard. However a large scatter in the data was obtained for the out-of-plane elastic constants, particularly as regards the transverse shear moduli.

In this paper we propose the SCT tester as a vehicle to indirectly measure the transverse shear modulus of thin paper grades. The test has several advantages, as it is a fast and well defined test with a clear interpretation of the result. At first, the load at compressive collapse is assumed to be governed by the Engesser–Timoshenko theory for column buckling. This gives an estimate of the transverse shear modulus, which subsequently will be used in FE-simulations of the SCT. Apart from providing an answer on how accurate the first estimate is, the FE-analysis could potentially also be used to obtain more accurate values of the transverse shear moduli.

2. Materials and methods

Beside the SCT testing, several tests were conducted in order to characterize the physical and mechanical properties of the paper. All measurements were performed under climate controlled conditions of 23 °C and 50% R.H. Each measured property was measured 10 times on each of five different sheets.

2.1. Paper

Papers were made in two grammages, 30 g/m^2 and 50 g/m^2, in a dynamic sheet former from a fibre furnish blend of bleached chemical pulps of eucalyptus (Södra Gold Eucalyptus) and pine (Botnia RMA Pine 90). The dry weight blend ratio of these pulps was 75:25, respectively. Eucalyptus hardwood fibres enrich softness of the paper whereas the pine softwood fibres enhance the strength properties of the paper (Shackford, 2003). No additional refining was applied to the pulps because, in tissue making, hardwood pulp is usually unrefined and softwood pulp is refined only at low level. Moreover, supplementary process chemicals such as retention aids or wet strength chemicals were not added to the pulps.

The formed paper sheets were pressed in a roller press between blotter papers and press felts at 3.0 bar nip pressure and at a speed of 0.12 m/s to a moisture content of about 62%, after which the sheets were restrain dried on the same blotter papers which were used during pressing. The blotter papers were Munktell 143025 and the quality was 1600. Drying took place under climate controlled conditions of 23 °C and 50% R.H.

The moisture content of the dried paper upon measurements was approximately 6%. The moisture content of the paper was carefully monitored and the paper was handled in climate controlled conditions, as stated above. This was done due to the fact that the mechanical properties of paper are much affected by the