Rethinking the Determination of Wet Strength of Paper

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The wet strength of paper is an important physical property, especially for household paper, *e.g*., paper towels, as well as for some functional paper grades. However, in the literature, various conditions of immersing the samples in water before testing have been reported, resulting in differences in their extent of saturation and inconsistency in the testing results. Also, the dryness of paper specimens before the wet-strength testing is a critical parameter for the wet strength of paper; however, this aspect has been neglected in the literature. In this editorial, the methods of examination for both the temporary and permanent wet strength are discussed. A more reasonable method is proposed, such that the wet strength is reported according to the immersion time and the initial dryness of the paper. As an option, the results may be expressed as a function of immersion time and initial dryness. In this way, the trend of temporary wet strength related to the immersion time in water can be expressed clearly and the permanent wet strength also can be evaluated comprehensively.

Keywords: Wet strength; Paper; Testing; Water immersion time; Dryness

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Wet Strength of Paper and Its Determination Method

Thanks to the recyclable, green, sustainable, and cost-effective nature of paper, it has found applications in many fields, such as printing and writing, packaging, household use (*e.g*., towels), and some special applications. The strength properties of paper are key factors that determine how widely and how well paper is able to be used. The wet strength is very important for such paper products as kitchen towels, paper currency, and various specialty products, such as bags and filters.

As its name suggests, the wet strength of paper is its strength after it gets wet. Likewise, the relative wet strength can be defined as the strength of the wet paper divided by the original strength when it was dry. The list of wet strength properties can be as long as the list of dry strength properties, *i.e.* tensile, tear, folding endurance, and so on. However, some of these wet strength properties are meaningless due to their low values. In TAPPI Method T456 om-3, which has been broadly adopted by global papermakers, the wet strength of paper is mainly defined as wet tensile strength. For paper grades with permanent wet strength, such as napkins and paper towels, applying a water immersion time longer than necessary to saturate the paper sample may not affect the test results of wet strength, as the wet strength of these paper grades are provided by crosslinking resin such as polyamide-epichlorohydrin (PAE), which is not affected by water. However, for some paper grades with temporary wet strength, such as facial tissue, the wet strength decays with increasing water immersion time. The specified temporary wet strength values of these paper products are usually achieved by addition of glyoxalated polyacrylamide (GPAM) chemistry, the effect of which lasts only seconds or minutes after moistening with

water. Therefore, water immersion time is a critically important parameter in testing the wet strength of such paper grades.

T456 om-3 details the specimen preparation, process of examination, and method of data collection and calculation. The suggested immersion time ranges from 5 to 40 s for easily saturated paper products, such as tissue, and from 2 to 24 h for other grades, such as paperboard, which can be difficult to saturate. These suggested periods of time are intended to make sure that the paper samples are fully saturated by water so that the variation in strength is less than 10%. On the other hand, the varying conditions of sample immersion time in water in the T456 om-3 method can lead to inconsistency in the wet strength results. We have reviewed relevant published literature regarding the wet strength of paper and found that the immersion time in water for wet strength examination of paper varied greatly, namely, 2 s, 5 s, 1 min, 100 s, 5 min, 10 min, 30 min, 1 h, 2 h, 12 h, 24 h, and overnight (Yang *et al.* 1996; Yang and Xu 1998; Lund and Felby 2001; Xu *et al.* 2004; Vander Wielen *et al.* 2005; Khampan *et al.* 2010; Sun *et al.* 2010; Aracri *et al*. 2011; Chen *et al.* 2013; Su *et al.* 2014; Ichiura *et al.* 2017). Another important factor affecting the paper wet strength, which has been neglected in the literature, is the dryness of paper specimens just before testing. It is well known that the initial dryness determines the paper strength of not only wet web but also rewetting phenomena (Hamzeh *et al.* 2013).

A Suggestion to Improve the Determination of Wet Strength of Paper

Based on the above discussion, we suggest to report the wet strength of paper as functions of the immersion time and initial dryness of paper. As an option, the wet strength may be expressed as a function of immersion time and the dryness of paper specimens. For instance, there could be a 3 D plot, in which the X-axis corresponds to the immersion time, the Y-axis is for the initial dryness of the paper specimen, and the Z-axis is for the measured wet strength. In this way, the temporary wet strength of paper may fully convey the specific information, which can also have direct comparisons with other results in the literature. Different immersion times in water for the sample can bring about undesired experimental errors. The inclusion of dryness of the paper specimen in the reported results also can give important information related to how the dryness of the sample affects the measured wet strength.

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