Filler Bondability Factor as a Tool for Maximizing the Potential of Mineral Additives in Paper Production

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Increasing filler content in paper while maintaining paper strength is a continuous need in the paper industry. The bonds between cellulosic fibers and fillers are essential to increase filler level in paper. Besides tensile strength, which traditionally has been used to investigate different fillers on fiber bonding, a new factor, *i.e.* a filler bondability factor, can be applied in evaluating the mitigation effect of filler addition on fiber bonding. This factor shows its effectiveness in optimizing the key parameters for filler modification and the choice of filler, and it helps to maximize the use of filler in the paper industry.

Keywords: Mineral fillers; Paper strength; Fiber bonding

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The Rising Need for Increasing Filler Level in Paper

As the second most used raw materials, mineral fillers play an irreplaceable role in cost reduction, optical properties, and printability improvement of paper. Such an irreplaceable role can be attributed to their lower cost, smaller particle size, and higher refractive index compared to cellulosic fibers, as well as to their special properties. Nowadays, paper mills seem to pay more attention to cost reduction brought by the use of filler, especially when the price of virgin fiber keeps staying at a high level. For example, laboratory data showed that when filler content is increased from 15% to 20%, there can be a savings of up to 8.3% in the consumption of electrical energy in refining, and the saving of steam energy in the drying section can be up to 9%. Therefore, increasing filler content in paper can offer considerable benefits to paper mills, and the need for increasing the usage of fillers in various paper grades is still rising for the papermaker.

However, strength loss limits the amount of filler usage in paper, as filler particles hinder the contact between fiber surfaces within the paper structure (Fig. 1). Based on this principle, many strategies have been developed to mitigate the negative effect of filler addition on paper strength (Hubbe and Gill 2016). These innovations, including optimization of filler particle shape, lumen loading, *in-situ* synthesis, filler pre-flocculation/co-flocculation (Zhang *et al.* 2016), and filler modification, can effectively strengthen the interaction between fillers and cellulosic fibers. Among these innovations, surface modification of fillers and the development of new fillers are still hot topics industrially and academically.

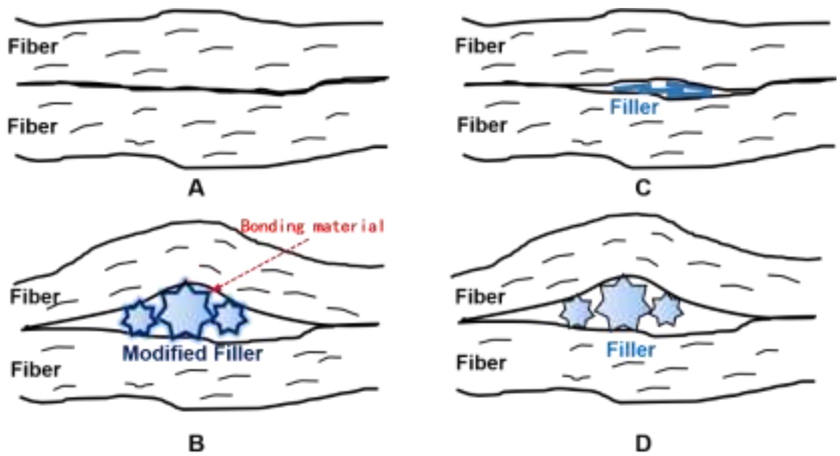

Fig. 1. Schematic illustration of bonding characteristics of (A) bonded fibers, (B) filler modified with bonding material, (C) and (D) different shapes of fillers.

Evaluation of Different Fillers on Fiber Bonds

Tensile strength, as an indispensable indication of bonding strength in paper, is commonly tested to investigate the effectiveness of new fillers or filling strategies in mitigating the de-bonding of fiber. However, the filler retention must be considered due to the variation of tensile strength by filler content. The experiments of evaluating effects of filler on paper tensile strength are typically designed in two ways. One is to make handsheets with different filler content for a given grammage, and the corresponding tensile strength is tested. Although filler retention may be varied from different fillers at a given filler addition, the trend of tensile strength is still comparable. The other way is to compare the tensile strength of handsheets with same filler content by adding different amounts of fillers according to filler retention tests. Whatever method adopted, handsheet making by the above methods and related tests is time consuming. Especially, when you optimize the key parameters of filler modification, such as dosages of chemical, reaction time, temperature, stirring speed, amounts of handsheets need to be made even though using experimental design, such as orthogonal experiment or response surface design. Therefore, a factor is needed to effectively determine the bonding between fiber and filler.

Filler Bondability Factor

The filler bondability factor (FBF) (Huang *et al*. 2014a,b) can be expressed as the following equation:

$$\text{FBF}=\frac{\text{strength of filled paper}}{\text{strength of unfilled paper}}\times\text{filler content of filled paper}\times 100$$

This equation includes two parts, *i.e.* the residual paper strength caused by filler addition, and the filler content in the paper. The former part is related to filler and fiber characteristics, as well as chemical aids, while the latter depends on the filler retention. For a given filler addition, lower loss of paper strength and more filler retained in paper indicates a higher filler bondability with cellulosic fibers. Therefore, FBF is useful in evaluating the bondabilities of various fillers at a given filler addition level by taking both paper strength and filler retention into consideration. Especially when optimizing key parameters of filler modification, FBF can reduce the amount of handsheets that need to be made. Besides, FBF can also reflect the interactions of fiber, filler, and chemical aids. Thus, it may be used to investigate the mechanism of filler addition on paper strength. However, some issues need to be addressed: (1) FBF is applicable only in cases where the amount of one filler significantly affects paper strength for a given filler addition. (2) In the cited work, the strength of the paper was determined in terms of tensile strength (Huang *et al*. 2014a,b). But other strength properties, such as burst strength or tear strength still need to be further studied. (3) Filler content in the paper should be higher than a certain level at which filler particles can significantly impact paper strength, *e.g*. 5%, because low filler content, *e.g*. 1% may help to improve the paper strength by enhanced paper formation. Besides, filler content should be within a factor of two of each other when evaluated by FBF.

Possibilities

Maximizing the use of filler without compromising the key properties of paper, such as strength, is a never-ending goal of papermakers. The filler bondability factor provides an alternative for papermakers to optimize the key parameters for filler modification and to evaluate new filler/filler blending for maximizing the potential of fillers, even to explore newly developed filling strategies for further understanding the mechanism of filler on paper strength.

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