

Critical properties of unmodified corn starch used in corrugating adhesives

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Cornstarch is the basic ingredient of most corrugating adhesives used in the United States. An estimated 900 million pounds are used annually in the U.S. corrugated boxboard manufacturing industry, the majority being unmodified cornstarch derived from hybrid yellow dent corn by a continuous wet milling process (Fig. 1). During the process, a number of measurements are made between the initial grading of the incoming corn and the different analyses run on each final lot of cornstarch.

Unmodified cornstarch has a consistent composition and chemical structure which behaves predictably in corrugating operations. It is a consistent mixture of two biopolymers of the basic repeating unit anhydroglucose, whose chemical structure is shown in Fig. 2.

The two biopolymers—amylose, a straight-chain molecule, and amylopectin, a larger, branched molecule—occur in a weight-to-weight ratio of about 27:73 in cornstarch derived from hybrid dent corn.

The physical and functional behavior of cornstarch changes totally when raw starch is pasted (i.e., gelatinized and dispersed). These differences are evident in standard corrugating adhesives such as that shown in Table I.

Following the cooking step, the pasted starch in the primary mixer formulation in Table I is tacky and viscous, and it stays suspended without agitation. Prior to the combination step, the raw cornstarch in the secondary mixer formulation is not tacky, provides little viscosity, and settles out if agitation is stopped.

When the pasted carrier starch combines with the metaborate formed by the reaction of caustic soda and borax, a pasted starch-metaborate complex is formed. This provides viscosity control and adequate suspension for the entire adhesive during the storing and metering of the finished corrugating adhesive (1). During the gluing operation at the flute tip, the raw starch in the adhesive also becomes gelled and consequently contributes to the bond development being effected by the pasted starch-metaborate complex.

Critical properties

Five properties of cornstarch critical to boxboard manufacturers are moisture, fluidity, caustic and borax sensitivity, form, and bulk density. The first three are usually measured routinely at a starch refinery. Also,

properties such as pH and protein often are routinely measured.

Moisture

Commercial cornstarch from a wet milling process contains loosely held water. Starch moisture content usually is determined by oven drying a sample according to an appropriate method.

The moisture content of cornstarch is extremely important to a boxboard manufacturer who uses starch in bulk. If it is too high, the starch may bridge in the silo and other parts of the dry handling system. Damp starch will support mold and bacterial growth. Starch that becomes too dry is more dusty and more explosive.

When the moisture content of starch falls within the usual range (8.5–12.5%), there is little change in the oven-dry solids of the adhesive. We studied the effect of starch moisture upon adhesive solids of a laboratory prepared, all-pearl adhesive. Across the starch moisture range of 8.5–12.5%, the adhesive solids ranged from 21.4% to 20.7%.

On the other hand, the moisture content of the starch has a significant effect on the viscosity of the corrugating adhesive. When we subjected the same laboratory-prepared corrugating adhesive to minimal shear, the Stein-Hall viscosity decreased from 485 s to 375 s as the moisture content increased from 8.5% to 12.5%.

Fluidity

An important property of pasted cornstarch is its capacity to impart viscosity to aqueous systems. Measurement methods include rotational viscometers, such as a Brookfield viscometer; torsional viscometers, such as a Brabender amylograph; and timed efflux viscometers, such as a Buel funnel, a Zahn cup, or a Clinton funnel.

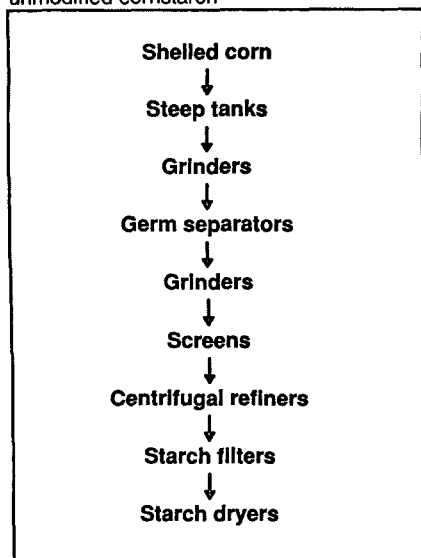
Alkali fluidity, when monitored using a Clinton funnel viscometer, is the volume of pasted starch at a specific concentration which passes through the calibrated orifice of the funnel in 60 s (2). The thinner the starch paste, the higher the fluidity. Generally, the lower the molecular weight of the starch, the higher the fluidity.

The alkali fluidity of unmodified cornstarch is the efflux time of 9.0 g of dry-basis pasted starch dispersed in 334 mL of 1.8% sodium hydroxide. The alkali fluidity of unmodified cornstarch ranges from 50 mL to 68 mL.

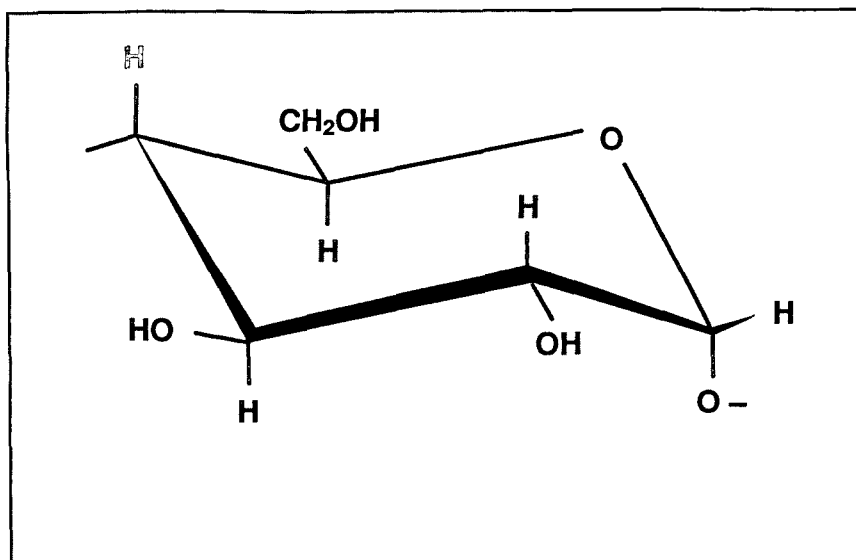
The fluidity of the cornstarch is important in the manufacture of boxboard because of the relationship between the fluidity of the starch used as the carrier and the viscosity of the corrugating adhesive. As the fluidity of the starch used in the carrier increases the Stein-Hall viscosity of the adhesive decreases. Across the fluidity

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1. Continuous wet milling process for refining unmodified cornstarch



2. Chemical structure of anhydroglucose repeating unit



range of 50 mL to 68 mL, the Stein-Hall viscosity of a laboratory-prepared adhesive dropped by 10 seconds.

The adhesive viscosity affects the transfer of the adhesive and its behavior on the flute tip since adhesive viscosity must be controlled to achieve satisfactory paper penetration, controlled dewatering, and minimal "slinging."

Sensitivity to caustic and borax solution

Raw starch should remain fairly inert during the formulation and storage of the corrugating adhesive in which it is used. Several useful tests have been developed to measure the tendency of raw starch to react with and build unwanted viscosity with the caustic and borax present in corrugating adhesives. These tests include a Brookfield viscosity measurement at 105°F of a 42% slurry of raw starch in a caustic and borax solution; a volumetric measurement of the settled starch below the clear supernatant resulting from allowing a slurry of raw starch in caustic and borax solution to sit overnight; and a gravimetric measurement of the amount of starch retained on a 200-mesh screen from an aqueous slurry.

High test values could indicate the presence of dryer-damaged starch. This occurs when starch is accidentally subjected to excessive heat at an early stage of the drying process, causing a partial gelatinization of the starch granules. Dryer-damaged starch in the secondary slurry portion of a corrugated adhesive can result in adhesive with a higher-than-anticipated viscosity. In this case, dryer-damaged granules behave more like viscous pasted carrier starch than like inert secondary starch.

When the raw secondary starch in a series of laboratory-prepared corrugating adhesives purposely was replaced with dryer-damaged starch, the Stein-Hall viscosities of the resulting adhesives increased according to the amount of contamination. This also was true of the responses of the three caustic and borax sensitivity tests to contaminated raw secondary starch. As the percent of dryer-damaged starch was increased, all three tests gave relatively greater responses.

I. Stein-Hall formula for a standard corrugating adhesive

Primary mixer	
Water	95 gal
Corn starch	200 lb
Caustic soda	34 lb
Heat to 160°F	Hold for 15 min
Water	60 gal
Secondary mixer	
Water	370 gal
Borax 10 mol	32 lb
Corn starch	1000 lb

Form

Two forms of starch—belt dried and flash dried—are produced by corn wet millers in the United States. Both forms are routinely used successfully in the preparation of corrugating adhesives, but there are some differences between the two which dictate that individual corrugators standardize on one of the two forms.

Generally, aqueous slurries of belt-dried starch are less likely to build viscosity with caustic and metaborate. When raw belt-dried starch is used in the secondary mixer, it seems to contribute less to the corrugating adhesive viscosity from a reaction with caustic and metaborate than does flash-dried starch at equivalent concentrations of caustic and borax.

The slurry viscosity test and the settled starch test appeared to provide a prediction of the Stein-Hall viscosity of adhesives made with flash-dried starches. The residue test had clearly related to the effect of dryer-damaged starch upon adhesive viscosity. However, the residue test was not useful in predicting the Stein-Hall viscosities resulting from the use of the different flash-dried starches, thereby indicating that additional factors can influence the behavior of the raw starch in a corrugating adhesive.

The greater tolerance of belt-dried starch toward caustic and borax may be due to the higher degree of order, or "crystallinity," of belt-dried starch molecules. Commercial steeping and other processing steps affect the degree of starch crystallinity (3), but the slower belt-drying process allows time for a more highly ordered arrangement of the starch molecules to occur. The nearly instantaneous flash-drying process minimizes the crystallization. The degree of crystallinity of cornstarch is measured by differential scanning calorimetry (DSC), which shows higher gelatinization endotherms for starches having higher degrees of crystallinity (4, 5). We found flash-dried starches having lower DSC endotherms than correspondingly more viscous belt-dried-starch-produced corrugating adhesives. Being more dense, belt-dried starch stirs into single-tank corrugating adhesives more readily and is less dusty than flash-dried starch. On the other hand, flash-dried starch is lighter and finer, therefore easier to convey pneumatically.

Bulk density

Bulk density, the weight of one cubic foot, is important to customers who use and transport cornstarch in bulk.

Generally, a value for loose bulk density is determined by gently filling a tared volumetric container before weighing it. A packed bulk density is determined by mechanically causing the contents of the volumetric vessel to settle before re-reading the volume. Packed bulk densities for both belt-dried and flash-dried starches are higher than loose bulk densities. Packed and loose bulk

densities generally are higher for belt-dried starches than for flash-dried.

Bulk density affects the amount of starch that can be held by silos and weigh-bins as well as by trucks and railroad cars. The storage capacity of a silo having a finite volume varies greatly as the bulk density of the starch changes.

Conclusion

Cornstarch that consistently satisfies the specifications for moisture, fluidity, and sensitivity to caustic and borax, and which is of standard form and density, allows the preparation of adhesive that performs consistently from batch to batch. □

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