corrugated board holds a major position in the packaging world. The properties of corrugated make it a justifiable and important option to package products. Invariably, however, it competes with plastic packaging, which for many reasons has a large share of the world packaging market. The battle to reposition corrugated board as a renewable and recyclable product has led to the present relatively stable market share.

To maintain this division of corrugated versus plastic requires corrugated board suppliers to realise the challenges of manufacturing. The cost of corrugated is largely dependent on paper and the industry seeks continuously to reduce paper content without reduction in board quality. Consistency of board
quality has become extremely important to be able to try and reduce paper content.

Modern corrugators are capable of addressing this issue well. Paper can be produced within strict quality specifications. Most paper used nowadays is recycled paper and is seen as a renewable and reusable material. Corrugated is, however, the result of combining several layers of paper together giving it unique properties and strength; the material to bond these layers together is primarily starch based glue.

The quality and consistency of board is the result of how the three ingredients — machine, paper and glue — working together. Machine capabilities are vast and most paper properties are nowadays reasonably well under control, whereas the glue is the product that still needs to receive attention to ensure correct specification to bond all the various papers under varying conditions.

Here is where our industry is still vulnerable. It is theoretically possible to make a glue that bonds 'everything' and to find other bonding mechanisms. The costs of such a glue and the possible other bonding processes would be prohibitive and would jeopardise the delicate price/performance ratio of corrugated board.

Allow me to give you some more general background on starch and glue and the various ingredients that have an impact on the manufacturing process of corrugated board. I do not claim this will cover everything, but it puts starch and glue in a wider perspective.

**Costs and Value**

As most corrugated box plants consider the starch adhesive used to bond liner to medium to be only 2 to 3 per cent of overall production cost, then why should they care about the quality of adhesive and starch equipment? The answer is quite simple. Glue has a direct effect on quality of the finished board, corrugator speed, warp and downstream efficiency, waste (remember this adds up very quickly), flat board and caliper, but most importantly on profit.

Starch is available from different sources. Most commonly used in the corrugated industry are corn, wheat, potato and tapioca starches. Many factors affect the consistent production of starch. As with any natural raw material, properties can be affected by temperature, hours of sunlight, humidity, rainfall, year of planting, soil moisture, plant population and fertilisation rate.

Starch is produced by numerous suppliers and normally available to be pneumatically conveyed to a storage silo where it can be loaded into bulk railcars, bulk trucks or packed into 25- or 50-kilograms bags, or super sacks of 500 or 1000 kilograms.

For corrugators, the most important properties are viscosity and gelatinisation point. These properties can vary from crop to crop. Data shows that natural gelatinisation temperatures vary depending on the climate or growing region of the world. Process modifications may be necessary to compensate for raw material variations.

Even granule size (diameter) is affected by environmental factors. Granule size is important since it is known that smaller granules have reduced amounts of amyllose, the linear molecule fraction in starch. Larger starch granules gelatinise more easily than small particles. It is also known that starches with high quantities of amyllose yield much higher gelatinisation temperatures than conventional starch.

When heated in water, native starch granules, regardless of molecular type, hydrate (absorb water), increase in size and thicken to form a viscous liquid, gel or paste. This single property is probably the most important characteristic of the starch and is relied upon to provide thickening. In the corrugating industry, this gelatinising property of starch is encouraged by the addition of caustic soda and used effectively to suspend or carry starch that has not been gelatinised.

Corrugated board is made up of liners and the fluted medium. Many weights, thicknesses and combinations of liners and medium are used for different applications. Starting at the single facer, flat corrugating medium is softened with heat and moisture and passed between a set of corrugating rolls to form it into flutes. Adhesive is applied to the flute tips on one side of the medium. Then, a single facer linerboard is brought into contact with the fluted medium under heat and pressure to produce a single facer web. This web is conveyed to the double backer station where adhesive is applied to the exposed flute tips and the double backer liner is applied. The combination is finally conveyed over a series of hot plates to set the adhesive.

**Commonly Used Processes**

A mixture of starch, borax, caustic soda and water is suspended in a paste of cooked starch. The addition of caustic soda helps gelatinise the starch. An increase in the amount of caustic soda, based on the total starch, will lower the...
Perfect Bond

High performance papers and the increased use of recycled paper, the porosity of the corrugated medium and liners has changed. Therefore, the adhesive must change as well. One option is to use modified, or carrier, starches, which, when used in conjunction with pearl starch, allow an increase in solids for better bonding and the ability to achieve higher machine speeds.

Viscosity

The term viscosity is used to describe adhesive’s flow ability. Since viscosity has great impact on the performance of the glue and the final bond we should elaborate on viscosity quite a bit more.

Low Viscosity means that the adhesive paste is too thin — the water tends to ‘disappear’ into the medium. This disappearing action may remove the needed water from the glue line, which means the starch may not have enough water to gelatinise completely. Many times the board will be dry and brittle coming off the corrugator, or may become brittle as the stack cures. If a pin adhesion test is performed on a sample of this board, low numbers will result. There may be very little fibre pull and the glue line will have an amber appearance. Since the bond is marginal, one solution is to open the glue settings on the machine to deliver more adhesive to the glue line. The downside to applying more adhesive is the potential for warp, washboarding, higher starch consumption and slower machine speeds.

High Viscosity means that the adhesive is too thick, it tends to sit on top of the flute tip, penetrating the medium and glue line very slowly. This will lead to a soft, wet board coming from the corrugator. It is difficult to print on wet board and it is hard to convert in the finishing department. Starch consumption will also increase because of the wide glue lines associated with thick adhesive. Adhesive flowability is reduced in the glue pans, which pushes adhesive to the back of the pans and allows heat to build up. This usually leads to gelling problems at the single facer. Overflowing...
adhesive and poor transfer of the adhesive from the glue roll is associated with high viscosity adhesive. On some of the new, high speed single facers, the machine will shut down if the viscosity is too high.

When one talks about viscosity it is important to realise that each viscosity is temperature related. Temperature is very important when taking a viscosity reading. The viscosity of the adhesive will vary proportionally with the temperature of the adhesive. As the temperature goes up, the viscosity will drop (become thinner). Conversely, as the temperature decreases, the viscosity will increase (become thicker). It is therefore important to always specify both viscosity and at which temperature it was measured.

**Effects of Shear on Viscosity**

Shear is the mechanical action of breaking down the adhesive resulting in reduced viscosity. Shear can occur at the mixers, pumps, pipes, elbows or valves, and at the actual corrugator. In mixing systems, mixing blades shear the adhesive to a workable viscosity. When an adhesive formula is developed, the mix times are calculated to perform this task correctly. When the mix times are changed, quality of the finished adhesive will vary.

The storage tanks should have agitators operating on timers. Agitators should be set to mix for five minutes out of every 30 minutes. The piping system used in the plant should not have dead ends. Fewer elbows and turns helps reduce friction and pressure buildup within the lines. The lines should be pitched to ensure adequate drainage for cleanups.

The pumps (often positive displacement pumps) used to transfer adhesive from the mixer to storage tanks and from storage tanks to corrugator can cause unwanted shear. It is important to have the proper size pump operating at the correct rpm. If air pumps are to be used to circulate the adhesive from and to the machine, proper air pressure is essential.

The length of time the adhesive is held in storage can be critical. Over time, the raw portion of the adhesive will begin to separate from the cooked portion. This causes viscosity to drop. Fast turnover of the adhesive is the best solution. Reducing the amount of material for storage during down periods is also wise.

Now, when you think we are finally done with viscosity, I need to disappoint you. All viscosities we measure keep changing due to the effects of pump shear and return to the main storage tanks. This is because the glue, after normal mixing, has not reached its threshold viscosity. In conventional mixing systems this change of viscosity is inherent with the type of mixing, mixing blade and tank size.

**Viscosity & Hi-Shear**

Measuring Viscosity of Finished Starch Adhesive

There is one well-known standard for measuring viscosity — Stein Hall seconds, which is calculated using a Stein Hall Cup. There are, of course, some plants and manufacturers who use other methods and tools for measuring viscosity. Love Cups, Zahn Cups, Brookfield Viscometers, Norcross Viscometers and Dynatrol Viscometers are some of the other methods and tools that are used. Some have individual charts for flowability, but most are converted to Stein Hall seconds.

The Stein Hall Cup is a brass cylinder with a specific size orifice in the bottom and two brass pins located on the inside of the cylinder wall. The distance between the two pins will hold a volume of exactly 100 ml of liquid. The cup is filled with adhesive and allowed to flow through the opening. The elapsed time it takes the adhesive to move from pin to pin is the viscosity in seconds.

The Stein Hall Cup must be calibrated properly to give an accurate viscosity reading. Measuring water flow from pin to pin is the best way to check calibration. Water should flow from pin to pin, through the orifice, in exactly 15 seconds.
Gelatinisation Temperature
The second important characteristic of glue is the gelatinisation temperature, the temperature at which the adhesive begins to thicken and develop its bonding properties. Although it is often expressed as a single temperature unit, in reality it is a temperature range dependent upon the molecular size and composition of the starch. The natural gelatinisation temperature of starch is generally too high for normal corrugating operations.

Running an adhesive with high gel temperature could affect bonding, especially at the double backer. Machine speed could also be affected. Addition of caustic soda suppresses the gelatinisation temperature, thus providing corrugators the flexibility to set the gel temperature at a desirable level for the individual machine conditions and paper combinations.

Gel temperature is measured by simply heating the adhesive as it is stirred with a glass thermometer. When the paste begins to thicken (gel), the temperature that appears on the thermometer is recorded.

If the gel temperature is too high, there may not be enough heat present to gelatinise all the starch granules. This will result in a white glue line and a poor bond. The speed of the corrugator must be reduced to achieve an acceptable bond, particularly on double wall board. The dry end operators also may notice wet or soft board coming off the machine.

If the gel temperature is too low, several conditions may result. The adhesive will gel before it has a chance to penetrate into the paper. This may result in brittle board, dry bond, raspy-feeling glue lines and cracking board.

Gel temperatures can and should be different for different application processes. A single facer glue is in direct contact with the hot surface of the corrugating roll and has a somewhat higher gel temperature to avoid premature gelatinisation. On the double facer however, it would make sense to have a somewhat lower gel temperature as the contact is by radiation only, especially when running double wall board.

Solids Level
The third important characteristic of glue is the solids concentration. High solids (starch) adhesives are necessary to bond high performance and recycled papers. Variation in the amount of starch or water changes the solids content of the adhesive. The higher the solids, the less water needs to be removed by the corrugator. To always use high solids glue would be prohibitive as it adds to costs and has very limited effect on the singlefacers, with the exception of E, F and other mini or micro flutes. It is, however, difficult if not impossible to mix higher solids with conventional equipment.

Processes, Systems and Equipment
Starch plays an important role in the corrugating process, so the integrity of the starch production process is critical. Four processes are common in starch adhesive production: Stein Hall, Jet Cook, High Shear and No-Carrier methods.

Basic adhesive preparation consists of a cylindrical primary mixer with a low-speed, high-torque mixer situated above a secondary tank with a high-speed, lower-torque agitator. This procedure is normally referred to as the ‘two tank system’ or sometimes the Pratt system. A drop valve generally controls the flow of adhesive from the primary mixer into the secondary tank.

The difference with a ‘one tank system’ is relatively small, in one tank you prepare the primary as in a two tank system, but add the secondary water etc on top. It saves equipment, components and makes process control less complicated. The most commonly used systems today are one tank concepts.

Stein Hall: This system uses a two-phase process. The first phase is referred to as the cook phase. Here, starch, water and caustic are combined to create a gelatinised starch adhesive. This product is also referred to as the carrier. The second phase is the blend phase where starch, water and borax are
added together and mixed with the cooked portion to form a finished adhesive. This is a simple mixing system allowing for a wide variation in viscosity, gel point and solids content. Improved performance is obtained by using specialty starches.

**Jet Cook**: This system is a modification of the Stein Hall process using a single vessel horizontal mixer. With the Jet Cook system, all the water, caustic and borax are mixed together with approximately half of the total starch in a horizontal mixer. The amounts of caustic and borax are determined by the gel temperature that is needed for a given adhesive. This starch/water/chemical slurry is then circulated through pipes and returned to the mixer. Live steam is injected into the pipe, causing the slurry to swell (gelatinise) as it is being pumped back into the mixing tank. Monitored by an automatic viscometer, the process continues until a given viscosity (set point) is reached. Upon reaching its set point, the steam is shut off and the remainder of the starch is added to the adhesive. A timed mix then finishes the process.

**No-Carrier**: This process is very different from the others. No gelatinisation of any of the starch takes place. In the No-Carrier process, starch, water, 50 per cent liquid caustic and boric acid are used to ‘swell’ the starch granule. This is accomplished by monitoring the viscosity of the adhesive. All mixing of ingredients takes place in a lower mixer. This process became redundant as it required a viscosity control that never failed. More recently these systems have returned to the market as control equipment has improved. The viscosity meter is used to trigger a step in the mixing process. Final viscosities may still vary and additives are needed to stabilise.

**Hi-Shear**: With the introduction of small batch glue mixing systems which utilise Hi-shear mixing technology it became possible to prepare glue quickly and with properties that address the specific requirements of certain papers and machine positions. Hi-shear is based on the Stein Hall process.

**Why Different Formulations?**

We have seen a shift to higher solids in the glue and in general this does improve the performance of glue, but still improvements are possible when we consider the vast difference in the application system of the single face and the double face. Single face bonding needs to be immediate as the two papers, fluting and liner, are only kept together in the machine momentarily. When the single face web is bonded with the second liner the time these webs are kept together is much longer and the pressure under which the papers are ‘pressed’ together is quite different from the single face position. A more adapted glue formulation is better suited for this application.

Once we speak of the second web of single face on the double facer, when double wall is produced, the differences are even larger since heat needed to create the bond between the upper web and the lower web is only transferred by radiation and not by contact.

To reduce the cost of board, papers used are of less fibre content and lower grammage weight. Paper surfaces are treated to have a better appearance, but these treatments have an impact on absorption rates. To accommodate these different paper properties it is possible that the glue formulation needs to be adapted for this purpose — higher penetration force or higher solids or both.

To try and produce all board with only one or two formulations means imposing restrictions on performance and possible quality. One option is to use different starches and additives. In many cases this does help, however increased (sometimes substantial) operating costs occur. In practice, a minimum of three to five different formulations are needed to address the requirements to consistently produce good board at high speed.
With all existing conventional systems, it is practically impossible to produce these different formulations in the time available. Batches of glue take 45 to 75 minutes to be made. Also, once made, the viscosity development is not finished, since it is not what we call the threshold viscosity. Because of the recirculation from storage tank to user station, the viscosity is further reduced. Sometimes this results in larger viscosity drops, which have a serious impact on application rates which operators need to correct and reset to ensure that the board made stays within the performance specifications.

Hi-shear mixing systems allow the user to make different formulations quickly and automatically — single facer glues with higher gel points and lower solids, except for mini flutes, to avoid excessive water and consequential low operating speeds or warp. Also, double backer glues that are higher in solids but lower in gel point, especially for double wall, where the upper layer gets radiation heat only. Since Hi-shear is based on the proven Stein Hall process, almost any viscosity can be made by only changing the ratio primary over secondary volume. Most important is that those viscosities remain constant after the batch has been made.

With the need to consider the environment and the impact of our industry on water consumption and pollution, systems that allow plant waste water to be used in the mixing process of glue have been introduced. Waste water, when treated, can be used in most systems, however the pH value of the waste water and residual starch may have an impact on the final viscosity of the glue if not compensated for. In a No Carrier system, the effect seems less as the process steps are triggered by reaching a certain value. The final viscosity, however, is not stable unless appropriate additives are used.

In a Hi-shear Stein Hall based mixing system, the final viscosity is based on the ratios and specifications of the raw material and albeit a stable and final viscosity, it can be different from the required viscosity if waste water was used. A simple remedy is to use waste water in the secondary mix only where the effect is minimal. Another more sophisticated remedy is to install a viscosity meter and have the viscosity controlled by varying the amount of primary. Since primary is normally added first, it requires a somewhat more complex arrangement to enable addition of primary at a later stage and mix this correctly.