Development of a tissue creping test rig

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Abstract

One of the key technologies in the production of tissue is the creping process, where the wet paper is adhered to a large drying cylinder and then peeled off the cylinder, when dried, with a doctor blade. The doctoring process changes the structure of the tissue, breaking bonds between the fibres, greatly increasing the thickness while reducing the length of the sheet and creating the soft feel of the tissue.

This paper describes a laboratory scale rig that we have built to investigate the creping process. The creping rig is fed by a continuous web from an unwind stand. The web is processed by spraying the desired level of adhesive, type, concentration and volume onto an internally heated cylinder, adhering the web to the heated rotating cylinder using a presser roll, and then doctoring the web from the cylinder and rewinding. Controllable parameters include spray rate, adhesive concentration and type, cylinder temperature, rewind tension and dryer speed. Creping effectiveness is measured on-line from the reduction in web length and from the force required to doctor the sample off the cylinder. Effectiveness is also measured off-line from the change in thickness, strength and stretch of the samples.

To obtain stable operation it is necessary to control the rewind tension. The solution finally chosen was to drive the rewind roll with a variable speed motor controlled from the tension from a measuring roll. It was necessary to stringently filter the adhesive to avoid full and partial plugging of the feed lines and spray nozzles. A two stage filter system was necessary, with one filter on the tank outlet and individual filters protecting each of the spray nozzles.

Initial results show that crepe ratio, tensile strength, thickness and stretch all fall with increasing web tension and temperature.

INTRODUCTION

In comparison to other types of papers, tissue is generally weaker, with higher stretch and greatly increased softness. Softness is a complex phenomenon, which incorporates many aspects of human interaction with the tissue product. It is believed to be influenced by both surface and bulk softness (Liu, Hsieh 2004). The surface softness arises from the interaction of human skin with the surface fibres of the product. Fibres which are partly separated from the rest of the tissue will be felt under even the lightest touch, enhancing the surface feel of the tissue. It is possible to estimate the surface softness using a sled method (Kuo, Cheng 2000), where the force required to drag a light sled over a tissue surface is measured. The Bulk softness relates to the sensation when tissues are crumpled or allowed to drape over a hand. Tissues which are bulky, ie with a low density, and weaker have better bulk softness. Most tissue softness testing is still done by experienced panels of testers although there have been efforts to predict tissue softness from a combination of mechanical, structural and surface tests (Liu, Hsieh 2004).

Tissue, like all paper, is manufactured as a wet-laid nonwoven. Water is then removed, firstly by vacuum assisted drainage, then pressing and finally drying at elevated temperatures. While other paper grades are simply dried by passing the paper over a series of steam heated cylinders, tissue is dried either using a Yankee cylinder or Through Air Drying (TAD) (Karlsson 2000; Ryan et al. 2003). The drying process is a key production step in producing tissue with the softness required by the market.

A Yankee dryer is a 7-8 m diameter steam-heated cylinder surrounded by a high temperature air impingement hood. Tissue drying with a Yankee cylinder involves spraying an adhesive layer onto the surface, pressing the tissue onto the adhesive, drying the tissue during the single pass around the Yankee and then scraping the tissue off with a creping blade. The process of removing the tissue is known as creping. The creping process partially destroys the bonds between the fibres as well as introducing a fine sub-millimetre wavelength corrugation in the tissue (Ramasubramanian, Shmagin 2000)

The chemical package used to stick the tissue to the Yankee surface generally comprises water soluble resin polymers with a release agent such as quaternary ammonium salts or hydrocarbons (Uner et al. 2006). The creping adhesives are believed to go through six stages during each rotation of the Yankee (Sloan 1991). Upon initial application, the polymers start to cross-link on the hot Yankee cylinder surface, following which the polymer is heated through the glass transition temperature and becomes tacky and the tissue is pressed on to the adhesive and the adhesive is rewetted by the moisture in the tissue. As the tissue continues around the cylinder, almost all moisture is removed from adhesive and tissue. The adhesive layer is split by the creping blade as the creped tissue is pulled from the Yankee surface, leaving a hard layer on the surface of the metal Yankee, which protects the surface from damage from the creping blade.

The properties of the creped tissue is determined by the blade angles and orientation to the Yankee surface at the creping point, as well as by the force required to split the adhesive layer, something which varies with adhesive package used and the application conditions. For example, an increase in the adhesive weight applied has been shown to increase the force required to split the adhesive layer and to reduce the wavelength of the fine corrugations developed in the structure (Ramasubramanian, Shmagin 2000), increasing the softness of the finished product.

The motivation for building the test rig described here was to provide a test facility for trialling new creping chemicals and determining their optimum operating conditions. The rig was designed to allow for testing creping chemicals to rank relative performance and so therefore to reduce the requirement for expensive full scale tissue machine trials of new creping chemicals. As such, the facility is unique to Australia and is one of only a few in the world.

EXPERIMENTAL RIG

Similarly to a tissue machine the rig is a web-fed, continuous process. It differs from a tissue machine in two main aspects. Firstly, it was impractical to fully replicate a tissue machine, given that such machines run at speeds of up to 2000 m/min with Yankee cylinder with diameters of up to 8 m. Instead the speed was scaled to the dryer cylinder size so that the residence time on the cylinder is similar to that of a full scale tissue machine. Secondly, unlike commercial machines where the web is formed, pressed after which it is stuck to the Yankee and then dried, this machine does not have a forming and pressing section. Rather rolls of a specialty uncreped tissue grade were used as the feed. Consideration was given to rewetting the tissue to around 50% solids content before adhering it to the Yankee cylinder, so as to more closely simulate the tissue machine. However, a wet sheet is very weak and would have required supporting fabrics to have been drawn through the Yankee and it would have been difficult to manufacture a drying cylinder with the required capacity. Accordingly, the rig is designed to simulate the creping of the dry web from the Yankee surface, rather than the full tissue manufacture process. Thus the properties of the tissue paper produced are not directly representative of the commercially produced product but rather provide a relative measure of how creping performance is likely to vary on the commercial machine when the adhesive, or creping conditions such as add-on rate or temperature, are altered.

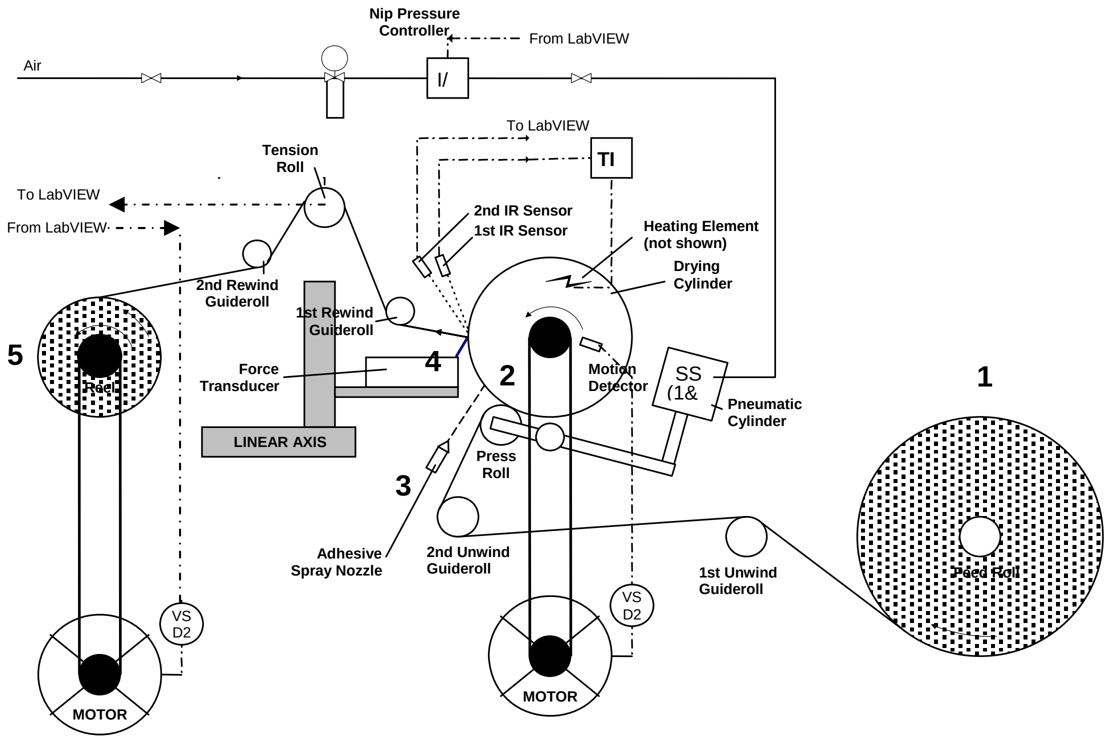

Figure 1. Pilot-scale creping rig schematic layout.

A schematic diagram of the creping rig is shown in Figure 1. The major sections of this rig include the unwind reel *[1]*, the press roll and Yankee dryer *[2]*, the adhesive spray system *[3]*, the creping blade *[4]*, and the rewind reel *[5]*. The dryer, spray system, creping blade and rewind system form individual modules, all resting on a bench with two linear rails, so that rearrangement to other configurations is possible. The Yankee dryer is electrically heated with a series of heating element rods, embedded into a thick-walled cylinder of cast iron. Operating temperatures typically vary from 120-160^{o}C. This dryer is powered by a variable drive motor, to a maximum speed of 85 m/min, although typical operating speeds are between 15-60 m/min, most often 15 m/min. The spray system consists of three tanks with full flow rate control –two containing adhesive formulation and the other containing water for dilution to other compositions during testing. The combined flow rate is then pumped through a series of two spray jets. The total rate applied to the dryer is between 200 – 400 mg/m^2. An overflow tray and a series of baffles limits the total quantity of spray reaching the dryer, and the amount of overflow is quantified to determine the actual quantity of fluid delivered. The creping blade is made from bronze to prevent scratching damage to the roll surface, and has a blade bevel of 17^{o}. The blade is activated by Festo pneumatics, which cause it to move horizontally along the linear rails to the Yankee dryer surface, pressed onto this surface usually at a force of 1200 – 1400 N. The rewind reel is motor-driven by a Baldor DC motor. A tachometer is placed on a rewind roll to provide feedback on the actual rewind surface speed, allowing immediate calculation of the crepe ratio[1]. The entire rig is operated and controlled via LabVIEW version 7.1Express, and all measurable parameters are logged for further analysis.

There have been several rig improvements in order to obtain stable operation. The creping process significantly shortens the length of the sheet due to the fine scale corrugations that are introduced into the structure and the rewind speed is less than the unwind speed, with the percentage difference being determined by all the factors that affect the creping of the sample. This then leaves the problem of how to set the rewind speed. The initial solution that was tried was to slave both unwind and rewind drives to the same speed, but to transmit the rewind force through a variable clutch reducing the rewind speed. The speed reduction in the clutch was controlled from the tension in the roll as it was rewound. This variable clutch proved unable to control the speed smoothly enough to avoid tension surges that frequently broke the sheet. The solution adopted was to directly drive the rewind with a separate variable speed motor and to write a

[1] Crepe ratio = (Yankee speed – rewind speed)/Yankee speed

control loop in Labview to adjust the speed from the measured rewind tension. This greatly increased the stability of the rewind tension, allowing much longer runs.

In order to achieve stable operation, it is also necessary that the creping be uniform across the width of the sheet. This proved difficult to obtain. It was necessary to achieve a uniform spray pattern of adhesive across the width of the Yankee cylinder as well as to ensure that the sheet was protected from drips at all times. This is because the creping force developed for a given blade configuration will depend on the tackiness at application, the thickness of the layer of creping chemicals and the degree of setting at the point of separation by the creping blade (Sloan 1991). Thus any variation in spray weight across the width of the Yankee will produce a varying crepe ratio across the width and an uneven tension across the roll during rewinding.

The resin polymer adhesives also tended to set in the feed tank, with the particles of adhesive plugging the spray nozzles. To control adhesive plugging two filters were used, one at the exit of the feed tank, and a second just before the spray nozzles. The rig was also set up with three feed tanks, one containing water, with the other two containing adhesive formulation. The standard operating procedure was then to start and end all trials running with water only so as to flush the system from any adhesive. Despite these precautions, the spray nozzles occasionally partially plugged with adhesive residue. To diagnose spraying problems, a valve was added to allow a shot of dye to be added into the feed line for the spray nozzles to provide an immediate visual measure of the evenness of the spray.

EXPERIMENTAL PROCEDURE

Uncreped tissue paper with grammages ranging from 19 gsm was used for the experiments.

Uncreped tissue paper was threaded through the creping rig and attached to the rewind to start the experiment, with the press roll engaged. The adhesive chemical was loaded into the adhesive tank/s and heated to 45^{o}C, along with water heated to the same temperature in the water tank. The Yankee dryer was set to the desired temperature and set in slow motion until temperature equilibrium had been reached. Water was sprayed onto the Yankee dryer when first applying the blade, and adhesive was gradually added in until the tissue paper stuck to the Yankee. From this point on the adhesive was increased to the desired level and the water reduced. Three major parameters were varied, those being the Yankee temperature, add-on rate and rewind tension. Each condition was maintained for approximately 5 minutes, tagged and analysed off-line for tensile strength, extension and bulk.

The creping ratio is defined by <u>Crepe % = 100x(Yankee speed – rewind speed)/Yankee speed</u> and provides a useful measure of the degree of creping on-line, i.e. during the experiment. Each sample was then tested off-line for tensile strength, bulk (the inverse of sheet thickness) and stretch. The parameter variations of web tension, Yankee temperature and add-on rate were assessed with respect to creping performance.

RESULTS

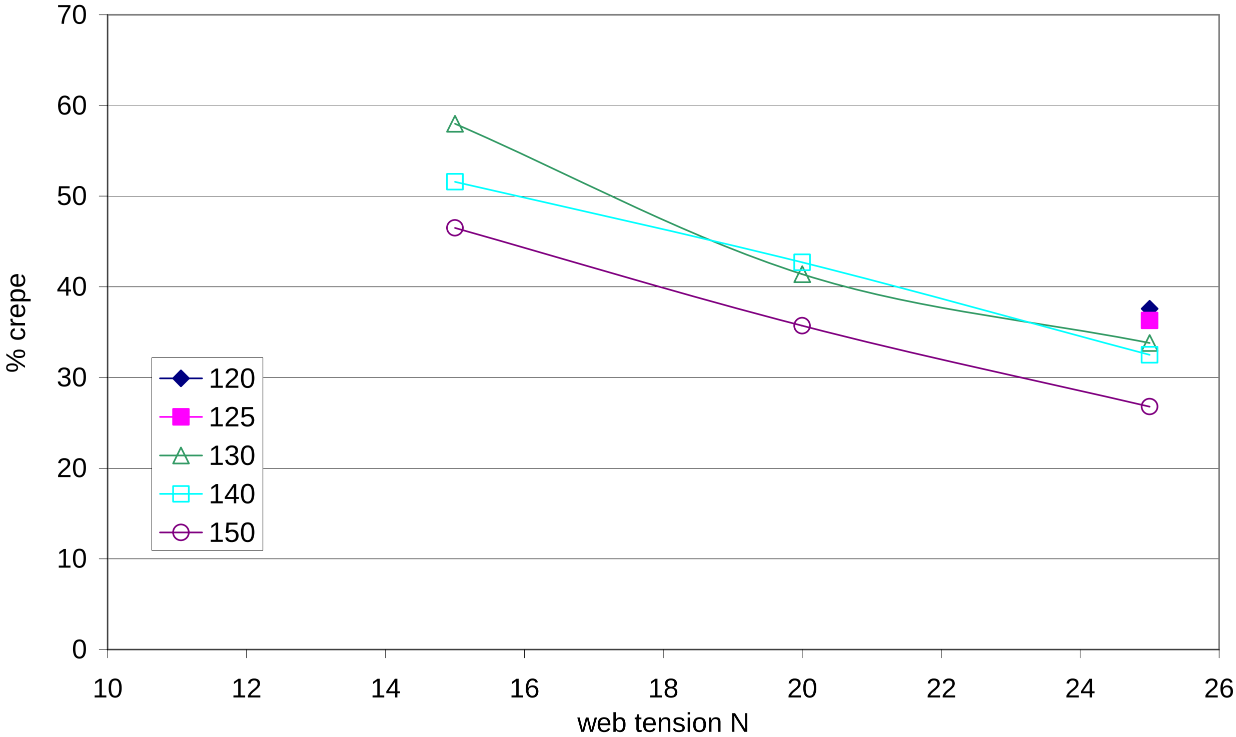

Figure 2 crepe % as a function of web tension at different temperatures for a 300 mg/m2 adhesive addition rate to the surface

Figures 2, 3, 4 and 5 show the % crepe, geometric mean tensile strength and stretch, respectively, as a function of web tension for Yankee cylinder temperatures ranging from 120 to 150°C.

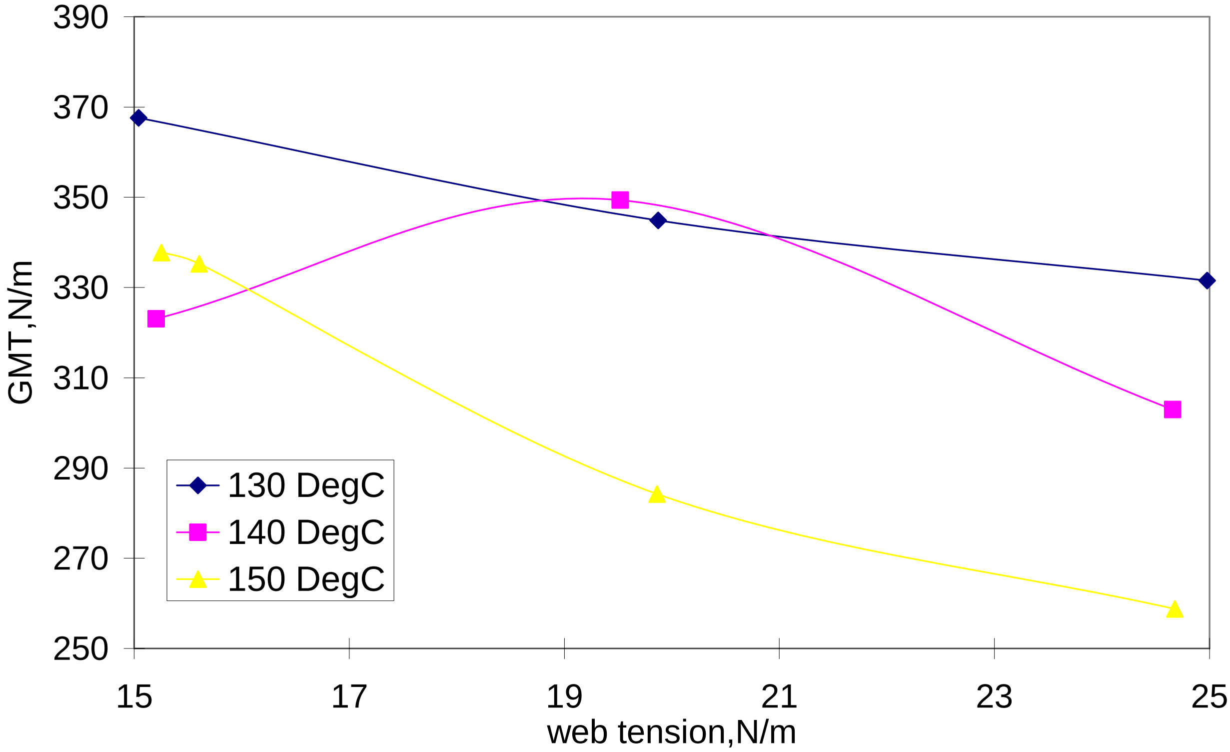

Figure 3 Geometric Mean Tensile strength (GMT) as a function of web tension and cylinder temperature for an addition rate of 300 Mg/m2.

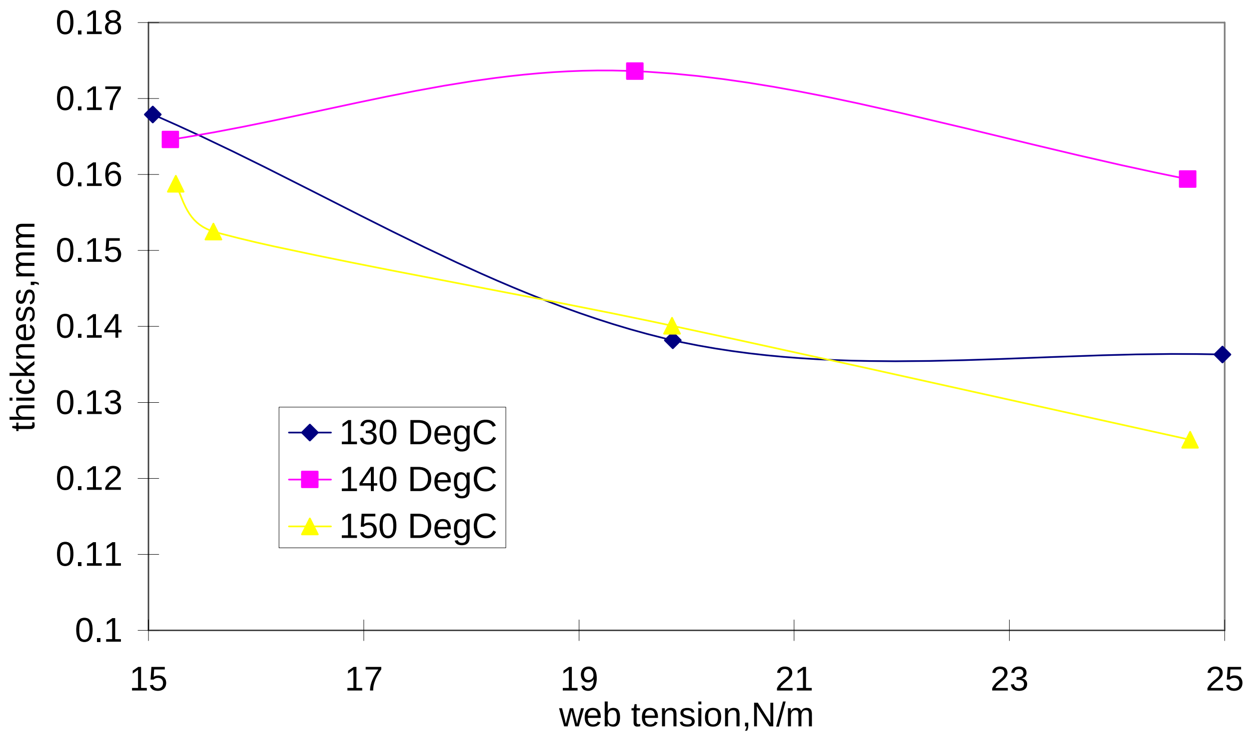

Figure 4 Sample thickness as a function web tension and cylinder temperature for an adhesive addition rate of 300 mg/m2.

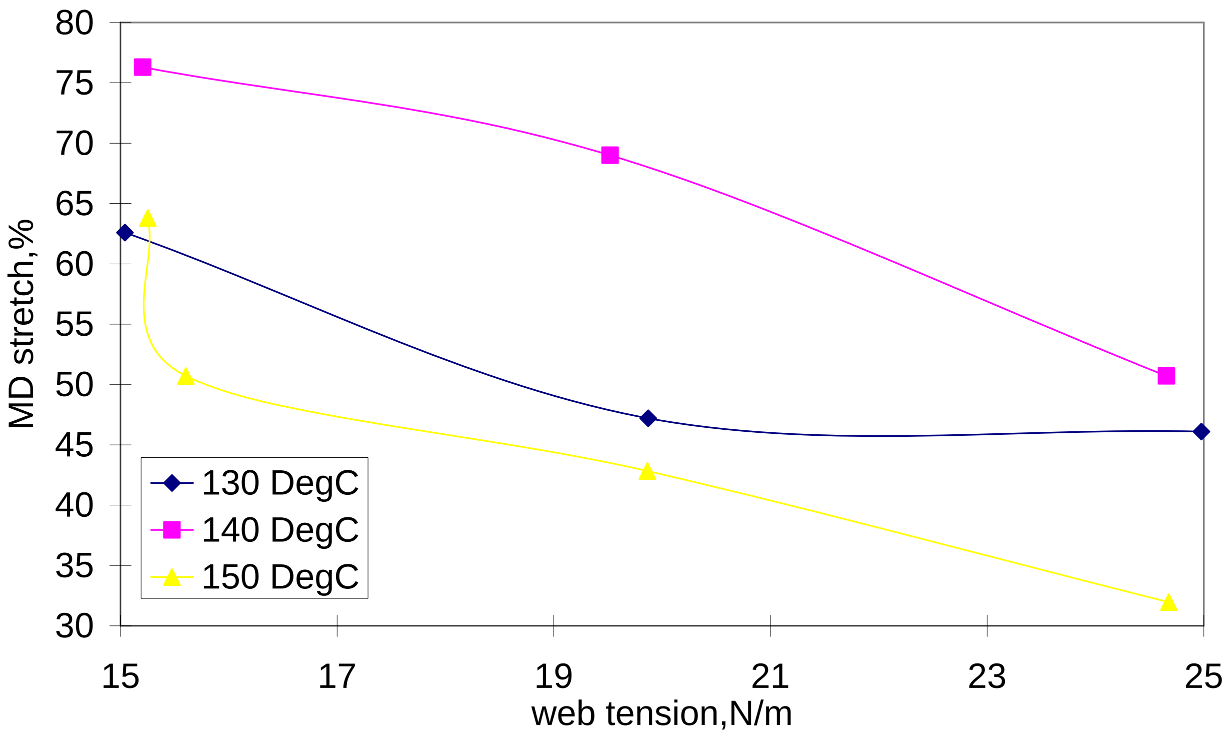

Figure 5 MD stretch at break (%) as a function web tension and cylinder temperature for an adhesive addition rate of 300 mg/m2.

All figures show similar trends with respect to tensile strength with all measured quantities falling as either the tension or the temperature was increased. At all temperatures, an increase in the rewind tension reduceds the crepe %. This effect arises because as the tension on the sheet, which pulls the sheet off the Yankee at the creping blade, is increased the amplitude of the crepes that are introduced into the structure decrease. This reduction in the amplitude of the crepes, increases the length of a given weight of tissue and thus increases the rewind speed. The corresponding changes in the tissue properties follow from this. For example, the thickness of the sheet will depend on the amplitude of the crepes and so this should decrease as the sheet tension is increased, as is observed in Figure 4. The effect of crepe ratio on the mechanical properties can be understood as arising from two effects. If the strength is the same, then the stretch should be directly related to the crepe ratio, since the corrugations introduced upon creping will be pulled out during tensile testing, thus allowing the sheet to display a very high stretch at break. It should be noted that the stretch of uncreped paper samples typically ranges from 1-5%. Tensile strength will be affected should the creping process introduce significant damage into the tissue structure, disrupting the bonds between the fibres. It seems clear from these results here that introducing large amplitude crepes at low tension introduces much less damage to the structure than smaller amplitude crepes at higher tension, thus producing the corresponding tensile strength results.

The effect of temperature is more complex, since it will relate to the strength of the adhesive layer at the point of creping, which is determined by the adhesive add-on rate and the level to which the adhesive has dried as it passes around Yankee. For these results, the strength of this adhesive layer appears to increase as the temperature of the cylinder increases, but the trend is not particularly strong.

CONCLUSIONS

A new rig to simulate the tissue creping process has been built. Initial results show that crepe ratio, tensile strength, thickness and stretch all fall with increasing web tension and temperature.

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