Mechanisms That Determine Tack Force Experienced By the Paper During Printing

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Keywords: printing forces, tack, nip impression

Abstract

During offset printing, delamination of the paper or paper coating can occur leading to serious print defects and press operation failure. A number of publications have reported tack forces that are measured during the printing of a solid region. However, often parameters are not clear the with regard to the effect of nip loading, speed, and ink rheology on this force.

A device that simulates the press roll is used to characterize the pressure pulse of an ink layer as it travels through a nip. The loading of the nip is controlled by air pressure. The speed of the rolls is well controlled by the computer. The pressure distribution is obtained with a flush mounted piezoelectric sensor. A series of Newtonian fluids are used on the roll surfaces as well as a series of inks that were rated for different ink tacks.

The pressure pulses are similar to past results with a positive pressure as ink goes into the roll, and a sub-ambient pressure as the ink splits. The magnitude of this sub-ambient pressure is called tack. Tack is a function of speed and nip loading, increasing to a point for both. However, at higher speeds, the tack becomes a constant value. This value must be related to the fluid being tested and its ability to withstand tensile force. A magenta ink had tack values that were three times the values of the viscous silicon oil. Inks with different tack ratings did not show the expected trend in terms of tack force in this device.

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Introduction

The forces that a paper web experiences during coating or printing are critical to understand for good design and operation of coating or printing processes. Large tack forces can cause a variety of printing defects such as linting or picking, where the paper sample delaminates at spots, leaving a white spot in the printed region, and a potential buildup on the press surfaces.

There are a number of methods to measure tack in laboratory settings such as those reported by Concannon and Wilson (1992), Xiang *et al.* (1998) and Gane *et al.* (1994). These tests are important in our understanding of the setting rate of inks as they contact paper. However, the magnitude of these forces are not well understood and the conditions around the ink film splitting is quite different than the actual printing event. Gane et al. (2003) did some work to explain the tack value in terms of extensional viscosities. There is a need in the literature to understand the process parameters that determine the magnitude of these forces for conditions that resemble actual printing.

A few standard devices are also available to measure ink tack. These are used to rate inks for different tack values. The most popular actually measure the torque required to rotate a roll that is in contact with one or more other rolls. This measurements has found much use and guidence in the development of inks and their prediction of behavior on the press, but this measurement also is quite different than the force a web will see at the exit of a printing nip.

A number of research groups have recorded the pressure distribution in a lab scale printing nip for cases of printing a continuous layer (Devisetti et al, 2002; Devisetti et al., 2007; Aspler et al, 1994; Ascanio et al., 2004; Johnson, 2003). These results are much closer to the actual printing event, but in all of these cases, not all of the parameters such as film thickness, nip gap or loading, and speed, are well known.

Here the effect of parameters on the nip pressure distribution is reported. The results using silicone oil, glycerin, a cold-set ink, and three inks with different tacks are given. Tests were performed on a rolling nip device with a flush mounted piezo-pressure transducer array. The sensors were dynamically calibrated using air pressure in situ to the device and resulting sensitivity factors yield a good correlation to line loading in the cross machine direction. The magnitude of the tack force is found to be a function of the fluid film thickness, fluid type, position along the roll surface, and velocity.

Experimental Setup

Figure 1 shows the laboratory device to study printing and coating systems. Both rolls are controlled by a computer using digital controls. The rubber covered roll

is mounted on a slide bearing that allows it to load against the steel roll when air pressure is applied. The loading force is generated by air pressure regulation and is calibrated with load cells. Therefore, the nip loading and roll speed are well known in the experiments.

Four pressure sensors on the lab press are shown as depicted in Figure 2. They are numbered from 1 to 4 where sensor 1 is at the center and sensor 4 is nearest to the edge. Spaced at 45 degrees relative to radial and tangential axis the sensors have spacing ½", 2", and ½" respectfully. These sensors are flush mounted in the steel surface and have a diameter of around 2 mm.

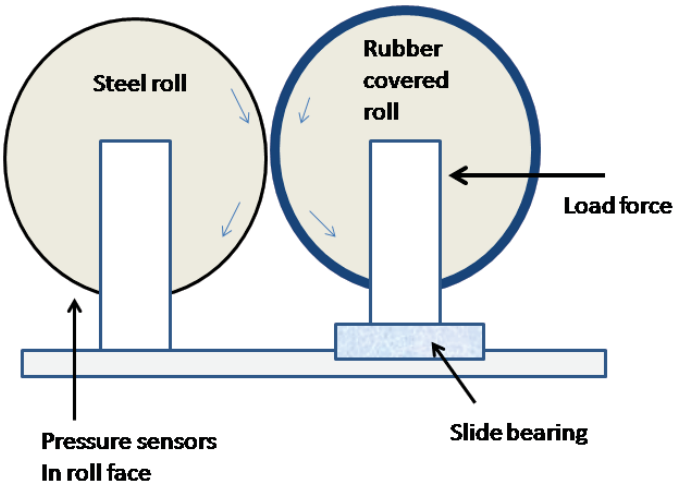

Figure 1. *Side view of laboratory press system.*

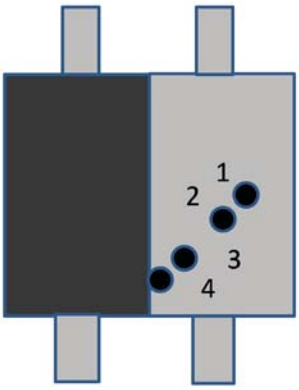

Figure 2. *Top view with steel roll on the right showing the pressure sensors 1-4.*

The pressure sensors are calibrated in situ using a home-made apparatus to apply set values of air pressure to each of the sensors. These pressure calibrations were used to calculate the integrated pressure profile: the integrated pressure should match the line load applied. The integrated pressure profile was compared to the applied nip

loading as shown in Figure 3. Excellent agreement is found in that the load force applied to the rubber roll is transmitted to the steel roll with the exception of sensor 2, which seems to clip some of the pressure values. It is not clear what is causing this issue with this sensor, but data from sensor 2 should be used with this in mind.

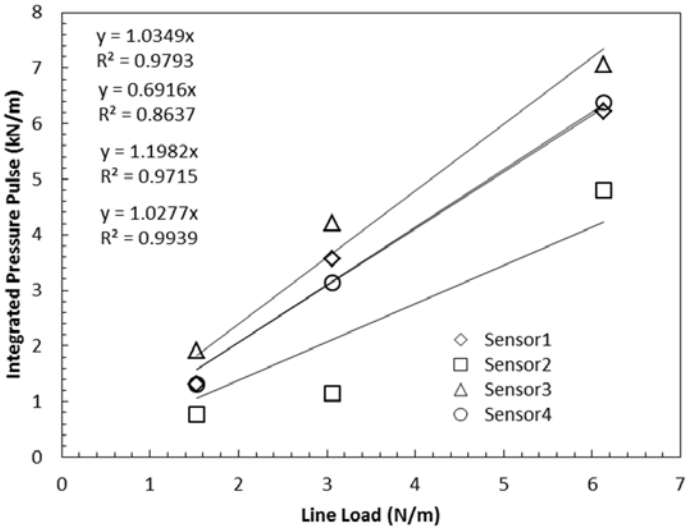

Figure 3. *Verification of pressure calibration with line load. Note the 1: 1 correspondence between integrated pressure profile and line load shows accuracy of calibration mechanism.*

Fluids were applied by syringe to the nip when the rolls are stationary but loaded together. Different amounts of fluid were used or a excess of fluid generating a pond of fluid in front of the nip. Inks were applied with a roller device or by printing in a lab press (Little Joe) onto a plastic sheet, which was then sent through the nip to ink the area of interest. This lab press was modified to allow quite thick layers of ink to be applied. Ink rheology was characterized by a controlled stress rheometer (Bohlin CVO) using parallel plate geometry.

A series of tests with three silicone oils (1, 12 and 60.8 Pas) and glycerine (1 Pas) were performed for different line loads, and velocities. For non-flooded cases, the volume is applied and then speed tests are taken for 0.5m/s, 1m/s, and 5m/s, in that order. For flooded cases, the volume was applied when necessary to keep a flooded state; flooding was determined visually as a small bead of fluid at the inlet of the nip. Nip loading was calculated from pressure axially applied to the rubber cylinder by two pistons and distributed to the steel cylinder by linear slides. Results were compared to coldset magenta ink and a series of low, medium, and high tack inks (all yellow inks supplied by Sun Chemical). These tack ratings were provided by the ink supplied as determined by the standard method.

Typical pressure signals are shown in Figure 4. Tack here will be defined as the magnitude of the minimum pressure that is measured because that is the tensile forces that would be of interest in picking and linting issues. This follows what others have done such as Aspler *et al*. (1994).

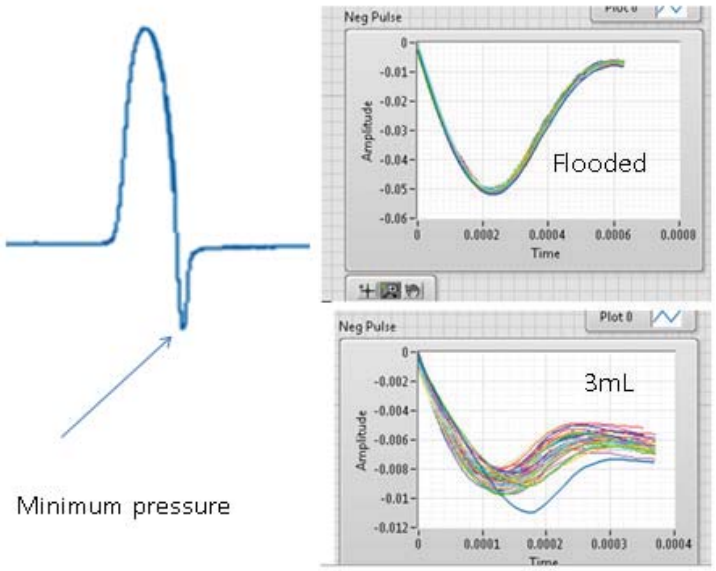

Figure 4. *Typical pressure pulses: left complete pulse, right negative pulses for flooded vs. 3mL of glycerin with 3.3kN/m line load, 5 m/s surface speed as measured by sensor 4 for glycerin. Note that the graph on the right of figure 3 shows the overlap of tack of 82 pulses which may varry due to trueness of the device. The variation is small when the tack force is large, but for small tack forces it is significant.*

Results and Discussion

Figure 5 shows the average tack values of selected sensors with silicone oil and glycerin. The typical standard deviation of these results is around 6% of the value. The results show that tack increases with velocity as expected, but the magnitude of that increase is not linear with speed. Also, the high viscosity silicon oil, at lower speeds, has a larger tack value than the low viscosity oil or glycerin, but it is not by a large amount: the viscosity of this oil is almost 60 times larger than the low viscosity oil, but the tack value is around three times larger. Both the velocity and viscosity results show that the tack value is not controlled by viscous flow but by some other mechanism. Therefore, some of the common parameters that are thought to influence the magnitude of this tack value do influence the result, but these do not scale as if it were simple viscous flow. It should be noted that the magnitude of the measured pressure is larger than 100kPa or one atmosphere for all fluids for the 5m/s case. This shows that these fluids are either undergoing cavitation or that they can withstand tensile stresses larger than one atmosphere for short time duration.

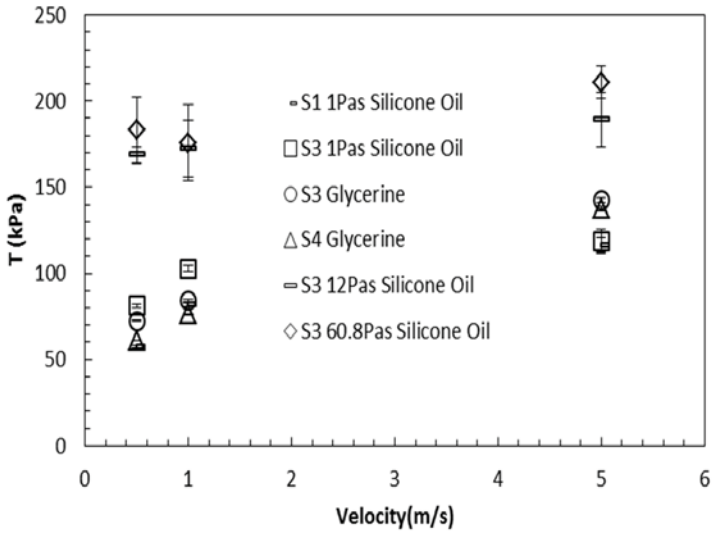

Figure 5: *Tack results comparing fluid types for flooded nip conditions and 3.1 kN/m nip loading. S1, S3 and S4 are the sensor numbers.*

Figure 6 compares the tack values for the flooded case with those with a finite amount of fluid. Fluid quantities of 1.0, 1.5, 3 and 15 mL correspond to film thicknesses on the roll surface of 5.5, 8.2, 16.4, and 82 μm, respectively. For the 3mL glycerin case we find tack decreases with increasing velocity. This may be due to the liquid distribution on the roll surface not being uniform even after several rotations. For the silicon oil cases, the tack force increases with velocity for all film thicknesses. We can see tack is largely a function of volume and only a weak function of velocity; a ten fold increase in velocity at most increases tack by a factor of two.

Misting of silicon oil was more pronounced than glycerin. Silicon oil tests were done at 1mL, 1.5mL and flooded. Neglecting misting and fluid application, standard deviation between subsequent pulses measured with one sensor are negligible.

Tack is shown to be larger at the edges of the nip for flooded conditions as shown by Figure 7 where sensor 1 is at the center of the nip and sensor 4 is located closest to the edge of the nip. Sensor 2 gives low values; this is expected to be caused by the clipping noted above. The cause for this variation is not clear at present: the nip is loaded in such a way that the force distribution should be uniform through the rubber roll. The roll is too short and stiff to have issues related to crowning or other factors such as this.

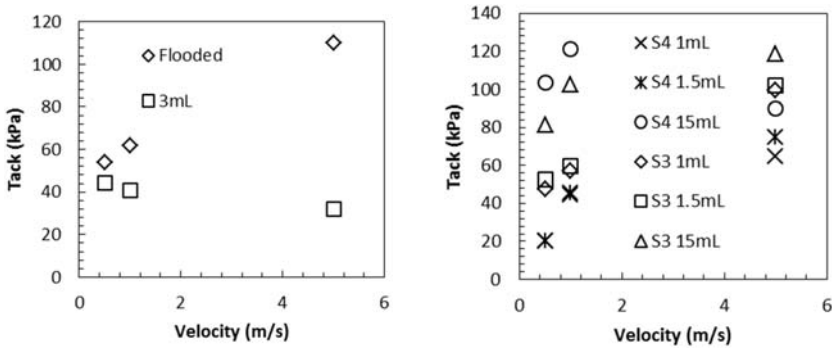

Figure 6: *Glycerine flooded and for 3 mL of applied fluid (left) and silicone oil (1Pas) at different volumes (right). Nip loading is and 3 kN/m for both plots. Sensors 3 and 4 (S3 and S4) are compared (right). 15mL is an estimate of the flooded volume.*

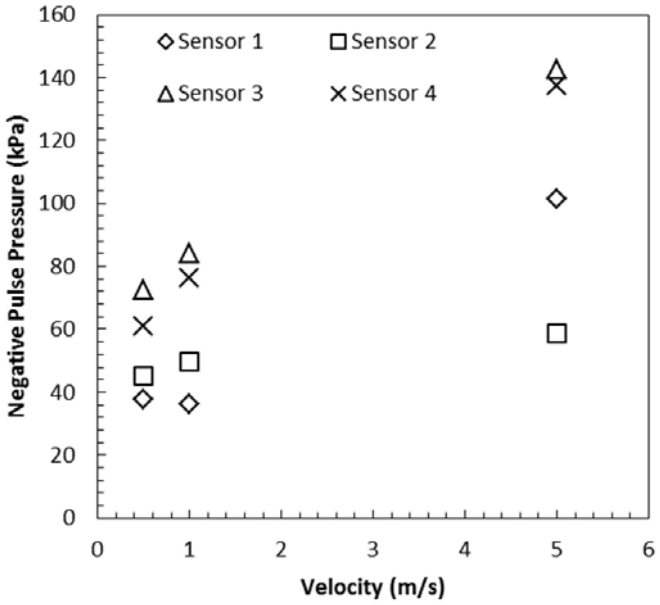

Figure 7: *Glycerine results with nip loading of 3kN/m.*

A magenta coldest ink with a low shear rate viscosity of 100Pas with Carreau parameters ($\lambda \sim 0.26$ and $n \sim 0.5$) was tested. Figure 8 shows the tack results for speed of 0.5-5.0m/s, a nip loading of 3kN/m, and ink volume of around 3mL. Again, the surprising result is that the increase in tack with velocity is not linear. The different sensors all seem to give similar results except sensor 1 at the high velocity. The magnitude of these values is larger than the previous results and all of the values are larger than 100kPa, even at low speeds. Again, this indicates that the ink may be close to cavitation conditions and the cavitation mechanism may be what controls the magnitude of the tack value: the pressure decreases at the nip exit but cavitation releases the stresses and keeps the magnitude of the force near 100kPa.

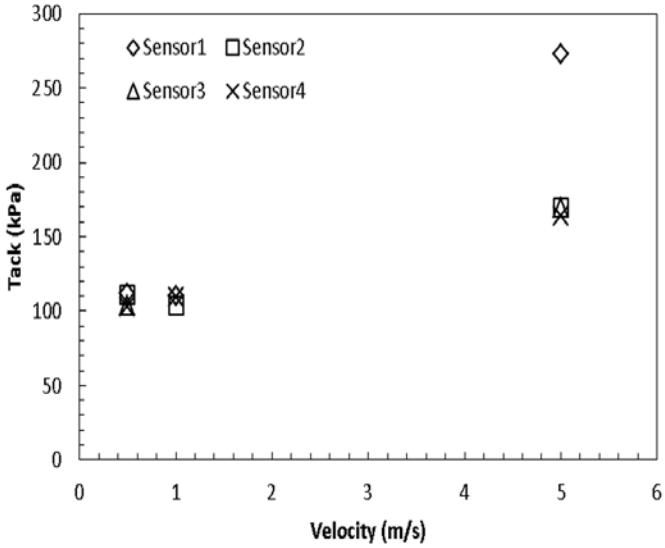

Figure 8: *Tack of magenta coldset ink at 1m/s and nip load of 3kN/m.*

When using ink applied as a patch, the steel surface is contacted with the ink film by running a printed sheet of plastic through the nip. The plastic was printed with the a bench scale printer. To apply more ink, a hand roller was used to apply ink to the steel roll in a uniform manner. Various coating methods and the resulting tack at different volumes and uniformities of fluid is shown in Figure 9. A glossy paper and plastic film are taped to the rubber roll surface to generate a situation that may resemble the actual printing event. The patch of ink with a significant thickness gave large forces.

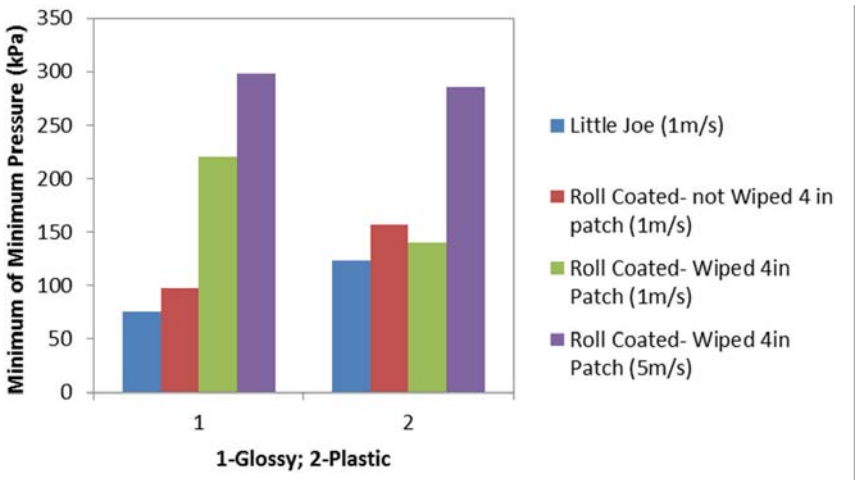

Figure 9: *Tack on paper and plastic taped to rubber roll at nip loading of 3kN/m.*

For the inks rated from low to high tack, 2mL ink was tested with no web on the rubber roll. Figure 10 shows the result for low, medium, and high tack ink: the values are even higher than the magenta ink but the tack values of the ink seemed to have no influence on the results. This result is quite a surprise in that it was expected that a high tack ink would show a high tack value in this test. The results also show that roll speed had minimal effect on the results.

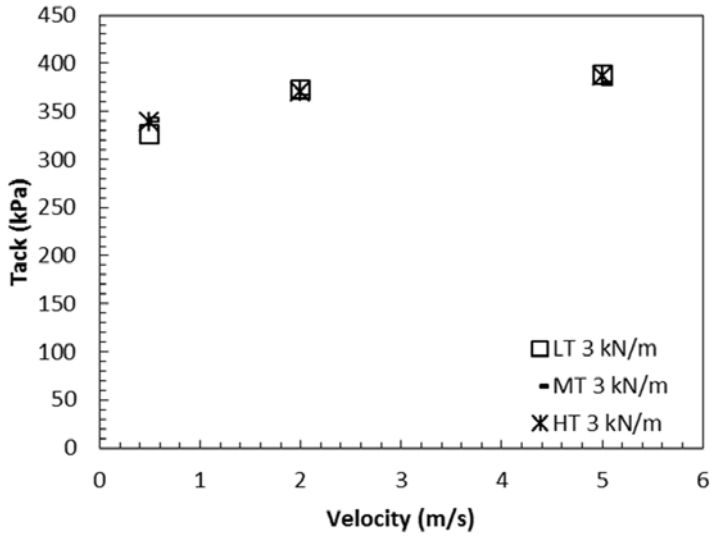

Figure 10: *Ink tack vs velocity for different line loads and ink tack (LT= low tack, MT= medium tack, and HT= high tack)*

Ink "tack value" obtained with the standard device does not significantly affect the tack force measured in this system even for other nip loading forces ranging from 1.5 to 6 kN/m. The device used to measure tack actually is recording the torque to rotate a cylinder loaded to other cylinders. The deformation in that device includes some shearing of the inks as well as normal deformation. A careful analysis of these results including modeling may explain this situation. For now, we expect that the tack value measured with this device is mostly controlled by the inks ability to withstand a tensile stress before cavitation occurs, not its shear or elongational viscosities.

Work of adhesion or energy is the integration of the negative tack pressure over the distance it acts on. This quantity can be calculated from the data by integration of the negative pressure signal. The work of adhesion also does not change with the tackiness of ink as shown in Figure 11 for the medium and high velocities. At the low velocity of the rolls, the work of adhesion seems to be a function of the amount of ink on the roll surface.

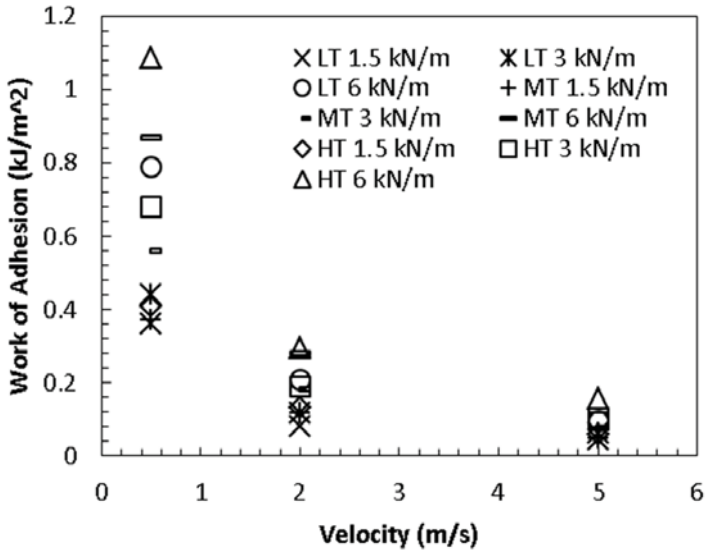

Figure 11: *Work of adhesion (integration of the negative pressure signal) vs. velocity for different low (LT), medium (MT), high tack (HT) inks for 1.5, 3, and 6 kN/m line loads*

Using the time of the positive pulse signal, the contact width can be estimated based on the roller velocity. The results for contact width are shown in Figure 12. As expected, high nip loads increase the contact width, regardless of the ink amount but again, the ink tack rating

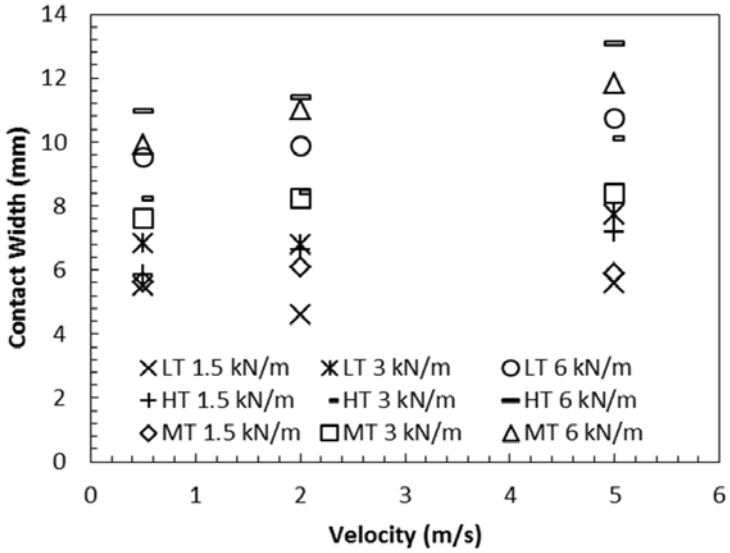

Figure 12: *Contact width of different tack inks*

One way to correlate various parameters is to use dimensionless groups. A dimensionless tack value T* can be defined in terms of the minimum pressure measured Pmin, viscosity μ, and the velocity *v*. Wp is the width of the fluid film in the nip, often around 200mm. The dimensionless loading parameter D* is formed from the line load used in the experiment P_L . These are shown in Eqs (1) and (2).

$$T^* = P_{min}\left(\frac{W_P}{\mu v}\right) \qquad (1)$$

$$D^* = \left(\frac{P_L}{\mu v}\right) \qquad (2)$$

Using these groups, the tack value can be related to the nip loading by seeking a power law type relationship as

$$T^* = AB^{*B} \qquad (3)$$

Where A and B are parameters. Table 1 compares the values of A and B for finite amount of fluid in the experiment for silicone oil and glycerin. The results are quite different between these fluids, but for the silicone oil, the values of A and B are in the same range. For the flooded cases, the values of A and B are reported in Table 2 for all of the fluids. For the high viscosity fluids, the value of B tends close to 1.0: this would indicate that the tack value is not a function of the viscosity-speed product because both quantities scale are scaled in that way. For the flooded case, glycerin seems to result in values of A and B that are in the same range for silicon oil.

	Silicone (1Pas) A/B		Glycerin (1Pas) A/B	
10mL	37.0	0.789		
3mL	27.6	0.814	0.888	1.145
1.5mL	53.3	0.684		
1mL	58.7	0.670		

Table 1. *Values of A and B that fit the data for the cases with a limited amount of fluid is used.*

Flooded	A	B
Glycerin (1Pas)	59.6	0.683
Silicone (1Pas)	16.2	0.885
Silicone (12Pas)	18.6	0.949
Silicone (60.8Pas)	23.1	0.930

Table 2. *Values of A and B that fit the data for the flooded cases.*

The result when plotted in terms of these dimensionless groups are shown in Figures 13 and 14. While there is some scatter in the results, they clearly show an upward trend. For the same viscosity and speed, this means that the tack force would increase with nip loading. This makes sense in that larger nip loadings would result in lower film thicknesses that should relate to higher tack forces.

Conclusion

The pressure distribution in a printing nip for various fluids and inks is measured with a laboratory device with flush mounted pressure sensors for a range of nip loading and speeds. The general behavior of the pressure signals agreed with past work. The tack values obtained do not scale linearly with velocity or viscosity, but seems to be controlled by some other mechanism rather than viscous flow. Offset inks have tack values that are larger than even the most viscous silicone oil. The tack value obtained with a standard device did not correlate with the tack value measured in this test. A correlation is developed to relate the measured tack to velocity, viscosity and nip loading.

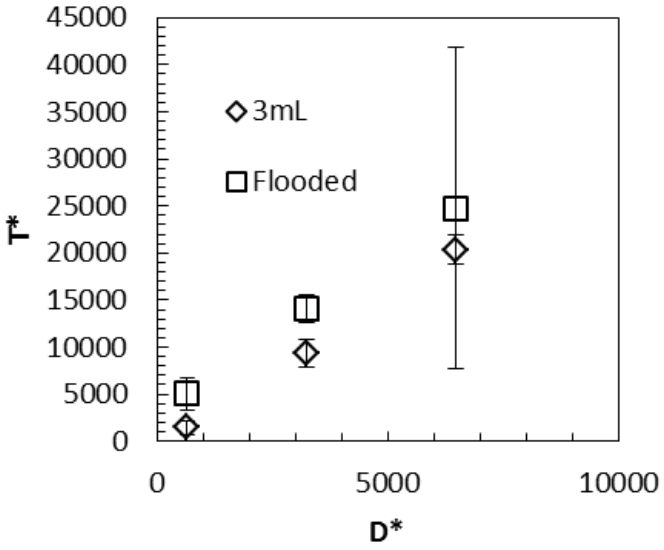

Figure 13. *Correlation of dimensionless loading to tack values for the glycerin case.*

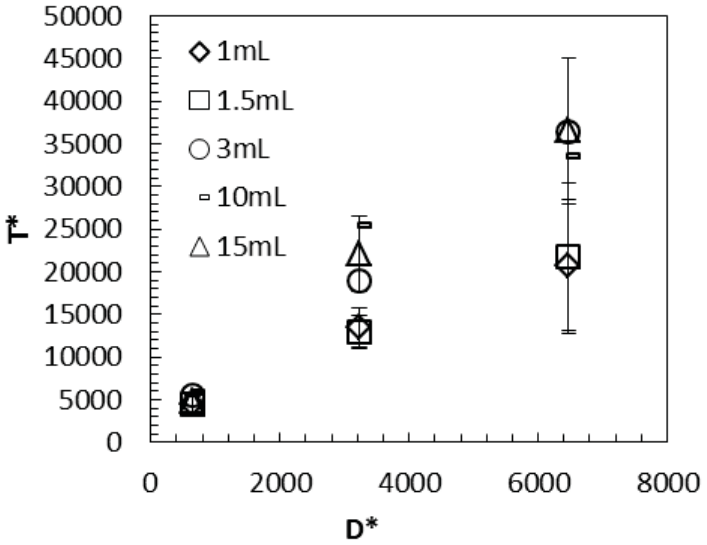

Figure 14. *Correlation of dimensionless loading to tack values for 1Pas silicone oil case.*

Acknowledgement

The authors thank the industrial sponsors of the University of Maine Paper Surface Science Program for their support.

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