Chapter 6

Conclusions and Recommendations

6.1 Conclusions

The contact resistance between the surface of heater rollers and plastic webs undergoing processing has significant impact on the heat transfer during web processing. The contact resistance between an aluminum sample to several smooth and rough plastics has been measured in the project. The aluminum sample was polished to a 25.4 x 10^{-6} mm surface roughness. The average aluminum surface to smooth plastic contact resistance was 0.0008 m^2-K/W. The plastics were produced by successive drawing and stretching through rollers polished to a similar roughness as the aluminum surface. The embossed sample that was measured, post embossing, had a contact resistance of 0.0028 m^2-K/W. The range of pressures in this study was 0.3 – 7.0 kpa.

It was impossible to measure the contact resistance of the entire range of plastics and processing conditions encountered in the spectrum of web manufacturing processes. This project however has succeeded in developing a methodology to measure the thermal contact resistance encountered in a new processing situation using a simple, static test apparatus. The

measured contact resistance can then predict the resulting heat transfer to the web in the actual processing conditions.

The lumped capacitance and distributed capacitance models discussed in chapter 2 can be used over a wide range of joint pressures and interface roughness. Both the plastic and the block roughness parameters have to be matched to the surface finish found on the actual process roller. The interface pressure is also an important parameter that would need to be matched. The static measurement technique is broadly applicable to different processing situations as there is no practical limit to either the interface pressure or surface roughness that can be simulated with the blocks. The Biot number parameter is the prime consideration in deciding whether to use the lumped capacitance or distributed capacitance model in the calculation of the contact resistance of the web to block interface. While the lumped capacitance model is easiest to use, with thin plastics the model can lead to large errors when the Biot number is above 0.05.

There is however a practical limit to the plastic thickness that can be used. With a high joint resistance, such as due to a large contact resistance or a thick plastic sample, the measurement time can be greater than 600 seconds. The energy loss to the surroundings can be 20% or higher of the total energy transferred between the two blocks. While the energy loss to the ambient is accounted for in both the lumped and distributed capacitance model, larger values of energy lost result in smaller a sensitivity of the measurements to the joint contact resistance.

The largest limitation of the static technique is that it is incapable of including the effect of air entrainment into the web-roller interface. The dynamic tests that were run at the American Roller Company Facility were an attempt to measure the effect of air entrainment at high web speeds. Given the large error in the dynamic measurements, their usefulness for estimating the contact resistance due to air entrainment is limited.

The challenge of getting accurate, reproducible contact resistance measurements from web and roller temperatures reduced the value of the measurements taken in the experimental aspects of this project. The contact resistance measured using an opaque PVC with the infrared sensor matched the static measurements within the margin of error of the tests. The effect of air entrainment at large speeds was not found to be discernable. With the polyester sample that was partially translucent to the radiation wavelengths used by the infrared pyrometers used in the study, the static and dynamic tests did not agree. The large error in the measurements could not be attributed to air entrainment as the measured contact resistances were higher at lower speeds. In his book on roller technology, David Roisum writes, "…the only sensor that truly reads what it advertises to is the ruler", and appropriately he writes this in his chapter on temperature control. Temperature measurement issues are the limiting factor in the accuracy of this projects, and his frustration is understood.

The use of narrow band infrared pyrometers would have reduced the error in the temperature measurements of the plastic webs. Narrow band pyrometers are sensitive over a small range of radiation wavelengths, and the wavelength range is centered around a particular absorption spectrum of the plastic of interest. Narrow band infrared pyrometers are

expensive, at around $6000 an installation. Due to their different spectral transmisivities, different plastics would require different sensors for acceptable results. The high instrumentation cost may be acceptable in a production application, but is prohibitive in research applications where different plastic samples would need to be tested.

6.2 Recommendations for Further Research

A better experimental method for measuring the temperatures of a web passing over a roller is needed. Other methods of measuring temperature for moving objects would be feeler probes, brought into contact with the web. A study of the relative errors from using 'feeler' probes vs. infrared pyrometers would be interesting. While paper webs temperatures can be accurately measured, their varying moisture and basis weight makes a comparison of the measured contact resistances to plastics difficult. Published contact resistance measurements for roller to plastic interfaces using narrow band infrared pyrometers would show if increased accuracy was possible with narrow band sensors. As narrow band sensors are used extensively in industry to control roller and resultant web temperatures, it would seem expedient to use existing web inlet and outlet data to calculate the joint contact resistance. A database of accurately measured joint resistances could be developed to aid the development of new manufacturing processes.

Heat transfer in nipped rollers has been extensively studied for the calendering of paper. Conflicting results have been published, but most studies have concluded that the

property variations of the web must be taken into account. A combined numerical and experimental study of the heat transfer and property variations within an actual embossing nip roller would lead to a much better method to predict the web outlet state from an embossing nip.

Axial temperature variations along the roller face have not been considered. Axial temperature variations would arise if there were significant heat loss through the roller support journals to the bearings. The edges of the roller would be cooler than in the midpoint of the roll. Temperature variation would not effect the contact resistance of the roller web interface, but it would effect the temperature profile in the web.