Developments in fast cleaning of thin films without wrapping

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ABSTRACT. In the display industry cleanliness of the materials used to build up the display is vital to avoid defects and most major manufacturers use rubber roller contact cleaning systems to remove any particles of contamination. As the films used in displays and backlights get thinner, this type of cleaning equipment can result in process issues relating to the wrapping of the sheets of film around the contact roller due to a variety of adhesion forces. This paper reports the development work done on a new cleaning roller system to alter several of the factors affecting the adhesion forces between the roller and the film.

The work reported includes

- Developing a new formulation of cleaning rubber to minimise tribocharging of the film
- Development of a new functional surface for the cleaning roller to modify the Van de Waals forces between the roller and the film
- Minimising the static charge environment within the equipment

This new cleaning system can process sheets of film down to 27.5 microns thick at speeds up to 20 m/min without creasing, wrapping or scratching.

1. INTRODUCTION. With the current drive towards electronic products which are thinner, lighter and more flexible has come the development of displays with similar properties. Films as thin as 30 microns are becoming much more common. When used in sheet format these materials pose significant challenges for contact cleaning technology which is commonly used by display manufacturers to reduce defects. A diagram illustrating a typical contact cleaner is shown in Fig. 1 Firstly, the film surfaces are often coated with functional polymers, sometimes giving a structured surface, which can have very high adhesion forces to the elastomer rollers. Secondly, the substrate has very little stiffness to help it resist bending. As a result, the film wraps around the elastomer rollers until the spring force generated by the bending of the material is sufficiently large to overcome the adhesion forces between the elastomer and the material. See Fig. 2.

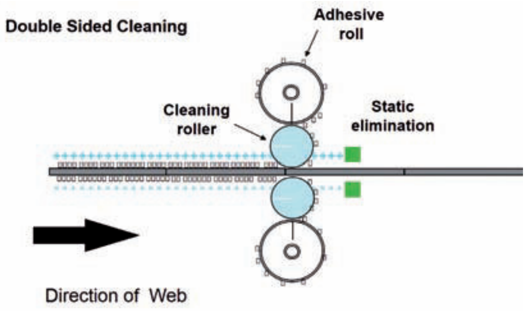


Fig. 1: Diagram of contact cleaning.

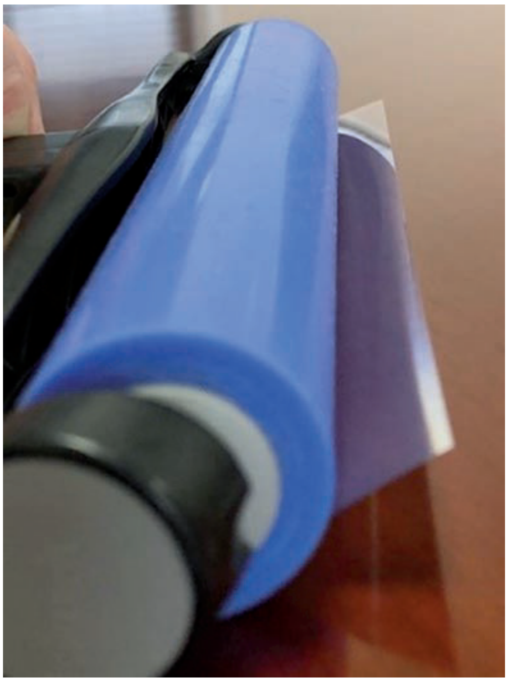


Fig. 2: Illustration of wrapping on cleaning roller

This wrapping mechanism generates damage to the material being processed and also causes significant production downtime in automatic production lines. These disadvantages have until recently outweighed the benefits of the defect reduction of contact cleaning. To overcome these issues a cleaning system had to be developed where the adhesion forces to the contamination would be great enough to allow the particles to be removed from the surface, while the adhesion to the base film surface is sufficiently low that the product will not wrap.

2. ADHESION FORCES. A literature search on contact cleaning revealed that very little research has been carried out on the removal of small particles from surfaces other than by fluid based technologies. The main focus of particle removal research has been into removing particles from silicon wafers using liquids, air or CO_2 snow. A few references to dry particle removal are found in work on improving the efficiency of xerographic processes where toner particles of a tightly defined shape and formulation are transferred by a roller to a paper surface. In contrast, the types of particle and the surface on which they are situated are not controlled in contact cleaning. However, several papers were found which detail the forces of adhesion holding particles onto surfaces and these formed the foundation for subsequent research work. One of these papers by R. Kohli [1] identifies the key adhesion forces and compares these forces as a function of particle size. Small particles can bond very strongly to surfaces through interactions such as covalent or ionic bonding, Van der Waals forces, hydrogen bonding, dipole-dipole, capillary forces and electrostatic interactions. Van der Waals forces dominate if the particles are small and spherical. Electrostatic forces become more important as the particles become larger and more irregular while a high humidity environment can increase the significance of capillary forces. A summary of force versus particle size taken from this paper is shown in Fig. 3.

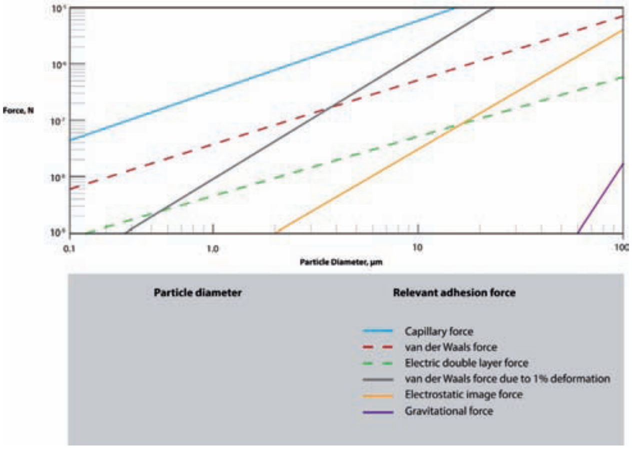


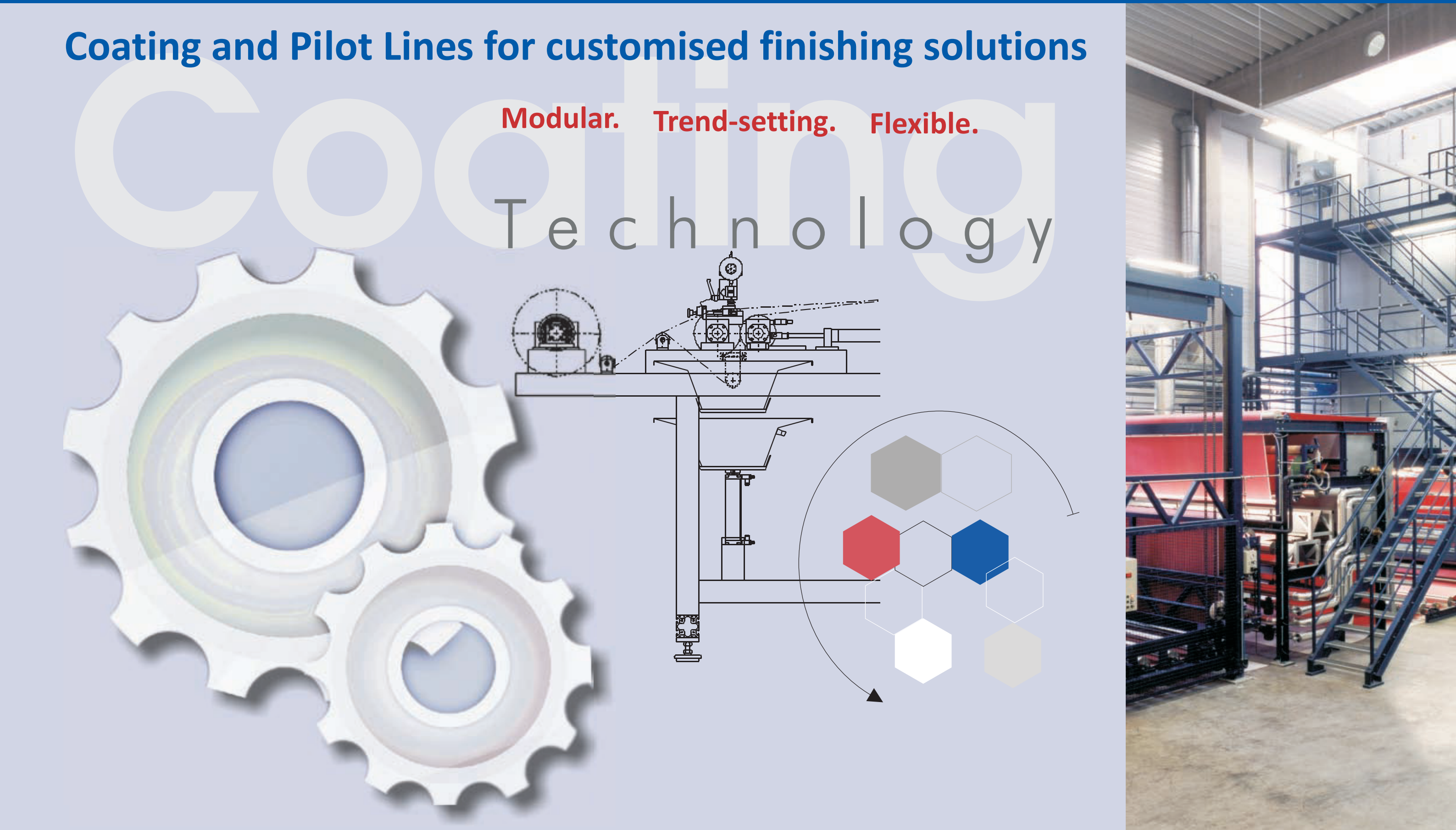
Fig. 3: Adhesion forces and particle size

Van der Waals forces can be described as the total force between polar and non-polar, but not ionic molecules. These forces play an important role in adhesion, surface tension, wetting and physical absorption as they exist between all atoms and molecules. There are three main interactions making up the total van der Waals force, namely, London forces which are attractive dispersion forces, Keesom interactions resulting from the alignment between two dipoles due to differences in electronegativity within a molecule and, finally, Debye interactions which occur when a freely rotating permanent dipole from a polar molecule induces and aligns with an instantaneous dipole in a non-polar molecule. London forces are the most dominant in terms of their contribution to the overall van der Waals force

Electrostatic interactions are formed between two solids when they come into contact. They can be formed from any charges on the particles, from electric fields that exist between the particles and the surface, by any external charges and by contact potential. Electrostatic forces tend to dominate particle adhesion when particles are of intermediate size from around 0.5 mm to 3 mm.

Capillary interactions between surfaces form due to water being present at the contact interface. These interactions are due to the surface tension of a liquid meniscus and the capillary pressure. These forces can be significant. Particularly when humidity is above 50%. Gravitation force mainly relates to larger particles.

Equations defining these adhesion forces are found in the references. [4][5][7] Work was done to analyse the equations defining the various forces of adhesion and a list of all the variable com-



piled, firstly, to identify the parameters which dominated the strength of the forces and, secondly, to select the variables which could easily be altered within the contact cleaning process. This is especially important as the exact properties of the surfaces to be cleaned and the type of particles which are to be removed are not under the control of the cleaning process. One specific parameter identified as being key to adhesion is the contact area between the surface and the particle since the forces of adhesion are greater as they are applied over a larger area.

The J Walz and N Sung [2] paper on the effects of surface roughness on Van der Waals and electrostatic contributions to particle to particle interactions and particle adhesion has provided valuable insight. The research strategy taken was based on the diagram in Fig. 4 from a paper by Drelich[3].

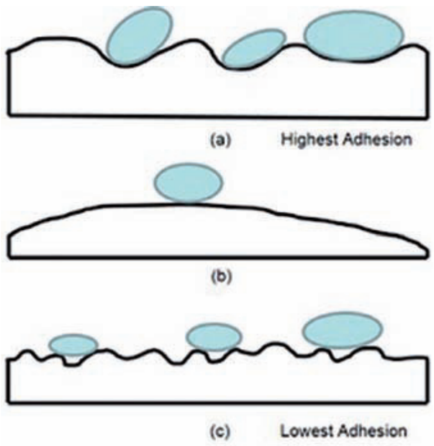


Fig. 4: Effect of roughness on adhesion

Having identified the forces on the particle to optimise the cleaning, a similar analysis was done for the interactions between the elastomer roller and the film surface.

3. EXPERIMENTAL RESULTS ON ADHESION FORCES. Having researched the theoretical aspect of adhesion forces, experiments were carried out to measure the actual adhesion levels between elastomer cleaning rollers and various surfaces, and also between different types of particles and surfaces. The experiments on the adhesion between the elastomer rollers and the surfaces were carried out on a macro scale using an Instron tensilometer with the sample surface horizontal in the bottom jaws and a sample section of an elastomer roller held in the top jaws vertically over the surface sample. The roller sample was lowered into contact with the surface, then removed vertically and the force measured. The results are measured in N/25 mm and are shown in the table in Fig. 5 for different types of elastomers and substrates.

Rubber	Cu	Steel	Kapton	PET	PC
Soft	1.17	3.26	0.51	2.55	2.37
Panel	1.49	3.32	0.81	2.63	1.07
Film	0.63	0.81	0.34	1.68	1.4
F3	0.11	0.11	0.11	0.85	0.12
Nano	0.08	0.04	0.07	0.75	0.34

Fig. 5: The table shows adhesion on various elastomer/substrates combinations

For the adhesion between a particle and the elastomer, the experiment needed to be conducted on a micro scale using Atomic Force Microscopy (AFM). The instrument used was a Digital Instruments Nanoscope lll Multimode microscope. The particles, from Duke Scientific Co., CA, USA, were made of silica, gold coated silica or polystyrene latex all with a certified diameter of 10 µm. The adhesion forces were calculated based on the force-displacement curves by using Carpick's toolbox. The adhesion values are in nN and are shown in the table in Fig. 6.

Probe	Silica	Gold	Latex
Soft	752	951	1027
Panel	848	823	847
Nanoclean	803	285	1073
Film	866	1152	1177
F3	1076	746	813

Fig. 6: The table shows micro-adhesion results

4. GENERAL MANAGEMENT OF ADHESION FORCES IN CONTACT CLEANING. As mentioned before, the roughness of a surface has been found to have a large effect on the adhesion force e.g. van der Waals interactions can change by several orders of magnitude. The difference in surface roughness is dependent on how large the asperities in the surface are compared to particle size. If the asperities are smaller than the particle then the particle will sit on the points of the surface giving a smaller contact area. See Fig. 4 (c) above. However, if the asperities are larger than the particle it will nestle into the hole resulting in a larger contact area. As shown in Fig. 4 (a).

To achieve a range of asperities to suit a range of different particle sizes the surface of the elastomer rollers has now been structured to provide a surface which on a macro level is rougher, providing less contact area to the film substrate and reducing adhesion between the roller and the film. At the micro level, the structuring provides asperities to increase the contact area to small particles of contamination and aid their removal.

Many of the adhesion forces increase with applied pressure. To minimise the pressure changes, the roller shafts have been made with carbon fibre replacing metal to reduce the weight of the roller while still keeping the straightness and stiffness required to maintain the contact area along the length of the roller. This has halved the applied pressure and reduces the adhesion forces proportionately.

5. MANAGEMENT OF VAN DER WAALS FORCES. To reduce van der Waals forces in a material the base chemical formulation was altered to reduce the dipole potential. This formulation change, achieved without additives, did not reduce the cleaning ability of the roller but provided a careful balance of properties needed in the chemical modification. This resulted in a small reduction of this type of adhesion force.

6. MANAGEMENT OF STATIC. Electrostatic adhesion forces play a very significant role in the level of adhesion forces, particularly in thin polymer films and this was a major focus of the development work.

Static electricity is the build-up of electric charges on the surface of an object. It is caused when two materials come together resulting in the separation of positive and negative charges. Electrons from one material will move to the other forming one positively charged material and an equally negatively charged material. This charge imbalance is retained when the materials are pulled apart. This is known as tribocharging. Conductive materials are least likely to become charged as the atoms are rigidly held and need a large amount of energy to flow.

In contact cleaning, the elastomer cleaning rollers are continually contacting and separating from the film substrate generating very large static charges through tribocharging. Because of the opposite polarities of the film and elastomer roller, the film is still attracted to the roller after cleaning. This only becomes an issue when the film is so thin that the electrostatic adhesion force is greater than the resistance to bending in the film, resulting in the film wrapping around the surface of the roller until the spring force of the film becomes greater than the electrostatic attraction.

The elastomers are inherently insulators and so the static charge can build up to very high levels. Initial research was into how to make the elastomers electrically conductive to a level where they would dissipate the static charge in a controlled manner. Traditional means of achieving this would be by incorporating carbon particles but for cleaning rollers, these have two disadvantages. Firstly, they significantly reduce the cleaning performance of the elastomers and, secondly, the particles are large and are not bound into the polymer matrix and can become dislodged, falling onto the part being cleaned, recontaminating it. Two different types of proprietary additives have been developed, one for each of the two main types of elastomer used to manufacture cleaning rollers. These have provided a surface resistance less than 109 Ohms which when connected to ground effectively dissipates the static charge reducing it to a low level. This, however, does not reduce the level of charge on the film. To achieve this, the level of charge generated by tribocharging must be reduced.

There are many tables indicating the relative tribocharging potential between different materials, however, few provide actual measured data. One reference which provides values has been published on the website of Alpha Lab Inc. [6] The tribocharging potential of the cleaning elastomers and some typical films from this website are shown in the table in Fig. 7 and the amount of

Material	nC/J
Polyurethane	+60
Polycarbonate	-5
Polyester	-40
Polyimide	-70
Silicone Elastomer	-72

Fig. 7: The table shows the difference in charge values

charge generated is assessed by the total difference in values between the two materials.

From the table, it can be seen that a polyurethane elastomer running in contact with a polyester film has a tribocharging potential of 100 nC/J while on a polyimide film it increases to 130 nC/J. To reduce this, a small percentage of a material with high electronegativity is added thus reducing the triboelectric potential of the roller surface.

Another way to reduce the triboelectric charge is by reducing the process speed as charge generation is directly related to speed. However, in a production environment a key metric is throughput and so this is not a viable option for many processes.

The table in Fig. 8 shows the effect these modifications have on the static charge environment with the cleaning equipment.

Position	Field Strength	Field Strength
	Original (V)	Modified (V)
Elastomer roller 1	200	20
Elastomer roller 2	900	20
Adhesive roll (Entrance)	2500	90
Adhesive roll (Exit)	3000	60

Fig. 8: The table shows reductions in static charge.

7. DISCUSSION AND CONCLUSIONS. In contact cleaning, producing an elastomer cleaning roller with balanced adhesion so that it can remove small particles of contamination from the surface of a film without causing it to wrap around the roller is challenging. This is especially true as films become thinner.

There is no control over the surface characteristics of the thin films being cleaned as manufacturers wish to maintain secrecy over the types of coatings they apply. Nor is there any control over the speed at which the user operates the machines. Even in clean rooms, there is no control over the amount of moisture or humidity condensing on the part.

The size, shape and material of the particles of contamination are rarely defined. Therefore, any cleaning roller has to be able to remove a huge number of different types and sizes of particles from a range of different films. These factors limit the options available for effective modification of the adhesion forces.

Identification of the parameters affecting all the main types of adhesion forces allowed the selection of those which could be modified to reduce adhesion forces. While the development work done on each of the individual parameters resulted in a reduction of that adhesion force, it is only by incorporating all of the modifications that the significant benefit of zero wrapping of thin films could be achieved.

These modifications result in a cleaning system which minimises the adhesive interactions with the film which has a larger surface area while maximising the adhesion of the elastomer rollers to the particles of contamination where the contact area is relatively low compared to that of the film. Previously, films 150 microns thick could wrap around roller surfaces. With the new system, 27 micron thick films can be processed at normal operational speed of 20 m/min without any wrapping or damage to the films. Optimising the balance of adhesion forces results in effective cleaning without wrapping and so considerably reducing overall defects.

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