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FOCUSING ON SURFACE RELATED ASPECTS OF MATERIALS SCIENCE

IN THIS ISSUE

EDITORIAL NOTES

This issue continues in the same vein as the previous by continuing to focus on the thermodynamics of surfaces in regard to surface forces and surface free energies as they affect both coating and particle adhesion. In essence our thesis is that the technologist who wants to apply a coating to a surface and his counterpart who might want to remove particles from that same surface have a common interest in the surface forces and surface free energy which determine not only how well the coating will stick but also how easy it will be to remove a given particulate contamination. In this regard we hope to organize the upcoming **TENTH INTERNATIONAL SYMPOSIUM ON PARTICLES ON SURFACES** and the **FIFTH INTERNATIONAL SYMPOSIUM ON CONTACT ANGLE, WETTABILITY AND ADHESION** in such a way that a joint session of the two symposia at midweek will include papers of direct interest to both camps. A cursory examination of the preliminary programs for these two symposia already indicates that a number of papers are of joint interest. At this time there is still an opportunity for anyone who would like to contribute a relevant paper to either or both of these symposia. In particular, wea encourage any work which is of mutual interest to both symposia. Finally, we always have a keen interest in any reader feedback concerning the organization and content of these symposia. Readers are encouraged to beam their comments to the editor at the E-mail address given in the masthead.

Now on to something slightly different but of definite interest to the adhesion and surface science community.

HAMAKER AND THE MIRACULOUS GECKO

The previous issue of the newsletter dealt with a number of theoretical aspects of Hamaker's deceptively simple equation for the attractive force between two closely spaced surfaces of neutral matter which interact exclusively by classical London - van der Waals dispersion forces. In this issue we explore a most interesting application of all that theoretical lore. It all starts with an interesting and delightful article by Prof. Kellar Autumn in the current issue of American Scientist[1] which discusses a number of technical issues concerning the gecko lizard's near miraculous capacity for climbing walls and scooting across ceilings with apparent total contempt for the law of gravity. Just to remind the reader who might not be up on his/her biology, the gecko is a small lizard typically a few inches long and found largely in the tropical and temparate zones of the planet. They come in a bewildering number of varieties such as the crested gecko (Rhacodactylus ciliatus), the gargoyle gecko (Rhacodactylus auriculatus), the mossy prehensile tailed gecko (Rhacodactylus chahoua), ... quite a long list, ...etc. For our purposes, however, what is most interesting about the gecko is its remarkable ability to scale vertical surfaces and hang from ceilings in a manner which seems quite oblivious to the normal action of gravity which holds pretty much everything else of nontrivial mass to the surface of the planet. How does it do it? One might first off hazard a guess that somehow it has little claws that by some mechanism manage to hook onto tiny asperities. I once got a dramatic demonstration of the climbing ability of the common grey squirrel. While strolling near the back of my son's grammar school, I happened to surprise a squirrel who was scavenging in the school dumpster. Upon spying me the little rascal jumped off the dumpster onto the wall of the school and proceeded to scamper up three floors to the top of the building. Quite an amazing feat. I came closer and examined the wall of the building which was made of red brick and observed that the surface was quite rough with many asperities on the order of a millimeter or so. I concluded that indeed the squirrel uses its tiny claws not only to climb trees but to climb any other rough surface. I was able to further prove this hypothesis since I have been engage in a long running battle to keep the local squirrels out of my bird feeder. The little varmints get into the feeder and hog most of the seed intended for the birds and make quite a mess besides. Let me tell you it is quite a challenge to thwart a squirrel since they are superb acrobats and can shimmy up or down the thinnest wire and jump amazing distances from a dead stop on the side of a tree. My strategy was to suspend the feeder far out on a branch (greater than 5 feet since I once saw a squirrel jump that distance from the tree trunk out to the feeder) at the end of a thin wire. My opponent Mr. squirrel

[1] "How Gecko Toes Stick", Kellar Autumn, American Scientist, **94 No 2**, March - April (2006) page 124.

was hardly phased by this amateurish defense. He simply slid down the wire onto the feeder and helped himself. Ah, but this is where I foiled the little rascal. One of my Uncles who also had several bird feeders had come up with an ingenious defense. He simply strung cylindrical plastic soda bottles onto the wire as a barrier to letting the squirrels pass to the feeder. The bottle has a hard and very smooth surface so the squirrel cannot get its little claws into it and the large diameter makes it a daunting obstacle. I spent many afternoons during lunch watching my furry friends try to get past the bottle barrier. They will try to hug the surface but the diameter is too large and the bottle tends to rotate also and the centrifugal force generated very efficiently ejects the marauding squirrel.[2] Thus we have a confirmation that in the case of the common squirrel the mechanism of adhesion to the surface is essentially mechanical interlocking of its small claws with the surface asperities. This is clearly not the case with our friend the gecko, however, since it can scale the smoothest plate glass as easily as it can scamper up a plant stem or any other vertical surface.

HOW DOES THE GECKO TOE ADHERE?

Prof. Autumn in his article systematically eliminates all the more obvious mechanisms which might come to mind as follows:

1. Does the gecko use some sort of adhesive glue? No, since the gecko does not have any glands in their feet which could generate such a substance and furthermore a glue would quickly become fouled by contaminants making it ineffective. Glue also poses a very sticky problem in that it is not easily reversible which is a primary requirement for gecko adhesion.

2. Does the gecko use some sort of suction mechanism? No again. Microscopic examination of the gecko's toes reveals only a vast array of tiny fibrils (setae) arranged in densely packed arrays which are clearly a hopeless morphology for a suction cup. Experiments were done in vacuum which found the adhesion for the gecko's toe quite unaffected definitely putting the kibosh on the suction mechanism. In addition a suction mechanism would lead to difficult problems when scaling relatively rough surfaces such as tree bark which present no problem whatever for real life geckos.

3. Can it be some sort of electrostatic mechanism? Sorry, this is not very likely since experiments have been carried out in highly ionized atmospheres which would quickly dissipate any excess surface charges but the gecko's toe still remains firmly planted.

4. How about capillary forces? Ever been in a restaurant drinking coffee or tea from a flat bottom cup resting on an equally flat saucer? Inevitably some of the liquid gets spilled onto the saucer and when the cup is set down a very thin film of liquid adheres it quite nicely to the saucer. On lifting the cup the saucer comes up with it. This can be especially embarrassing when trying to appear suave and debonair in company especially when gravity finally overcomes capillarity and the sauces crashes to the table. Sorry again. Prof. Autumn and his coworkers have demonstrated using contact angle measurements that the tips of the gecko's fine fibrils are ultrahydrophobic (θ = 160.9 degrees). In addition a group at the Max Plank institute headed by Eduard Arzt demonstrated very strong gecko toe adhesion at very low humidity.

So what is left? It turns out that the winning candidate is direct intermolecular interactions of the London - van der Waals variety. The evidence comes from two sources. First the morphology of the tips of the fine setae fibrils which form the surface pad of the gecko's toe was demonstrated to be a relatively flat spatula configuration by electron microscopy experiments performed by Rodolfo Ruibal and Valerie Ernst at the University of California, Riverside. This further ruled out any mechanical interlocking mechanism but did make a fairly large amount of surface area available for intermolecular interactions. The intermolecular interaction hypothesis was further clinched by Uwe Hiller at the University of Münster who demonstrated that the adhesion of the gecko's toe

[2] Not to worry about the squirrel injuring itself since it is such a small mammal that it can fall from nearly any height and hit the gound without injury. Mice and other small mammals have the same advantage. J. B. S. Haldane comments that he has seen mice drop down 100 foot mine shafts only to bounce off the floor and scamper away. "On Being the Right Size and other Essays", J. B. S. Haldane (Oxford University Press Paperback, 1985)

depended on the chemical properties of the surface in question rather than its texture.

ENTER HAMAKER

If we go on the hypothesis that it is essentially dispersion forces which control the adhesion of the gecko's setae to any given surface then we can put forward an amazingly simple mechanism for the gecko's adhesion. In essence we need to explain how the gecko manages to adhere its toe firmly yet entirely reversibly to any given surface. The mechanism must somehow involve a subtle manipulation of the myriad setae with their flat spatulate tips which form the surface of the gecko's toe pad. Basically our friend the gecko manages to bring a very large number of the spatulae into intimate contact with the surface by some sort of muscle action such as wrinkling its skin when it wants to adhere. Performing the reverse operation of misaligning and retracting the spatulae surfaces releases the toe allowing for further movement. In this way the adhesion of the toe is entirely under the control of the gecko's central nervous system which accounts for its well know agility in scaling walls and scampering across ceilings.

What we need now is some estimate of just how much adhesion force we can expect one of the seta spatula to generate using just dispersion interactions. This is precisely where Hamaker's simple formula comes in handy, but we unfortunately do not know the precise form of the Hamaker relation for a gecko spatula so we need to make some educated guesses. Going on what is available in the open literature[3] plus relying on data supplied by Prof. Autumn's article we can make a heuristic guess as to the appropriate Hamaker relation for the gecko spatula. We approximate the gecko spatula as being a small square area approximately 0.2 micrometers on a side and further assume that the substrate is an essentially flat infinite surface. Under these circumstances the interaction between the spatula and the substrate can be estimated as:

[3] See for instance "Fundamentals of Particle Adhesion", by Donald S. Rimai and David J. Quesnel (Global Press, 2001) and "Interfacial Forces in Aqueous Media", Carel J. Van Oss (Marcel Dekker, New York, 1994).

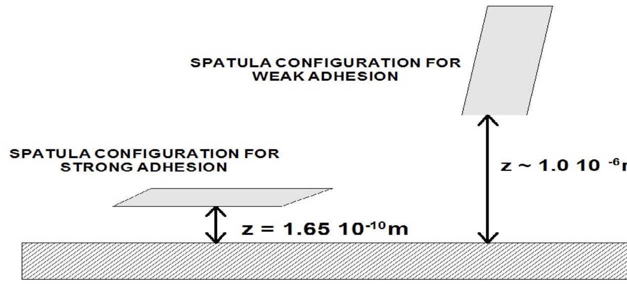

Figure 1: Model surfaces for estimating the adhesion force of the gecko's spatula to a flat surface. Adhesion is attained by aligning the surface to the substrate and bringing it in as close a contact as possible. Release is easily achieved by misaligning and slightly withdrawing the spatula tip. The stem of the seta not shown for purposes of clarity.

Where:

F = Attractive force between spatula and substrate
A = Area of spatula
z = Gap distance between spatula and substrate

Figure 1 illustrates the assumed geometry of the spatula and substrate for adhering and nonadhering configurations.

The values of the constants in the Hamaker relation are again estimated on the basis of what is available in the literature and from data supplied by Prof. Autumn's article. The size of the gecko spatula is about 0.2 micrometers on a side so the area can be taken as $4 \times 10^{-14} m^2$. On the basis of a casual survey of published data a reasonable estimate of the Hamaker constant is roughly 10^{-18} Joules. The distance of closest approach of the spatula to the substrate surface is estimated as 1.65×10^{-10}m which is sort of consensus value arrived at again from a literature survey. It should be noted that all of these numbers are rough estimates but they should nonetheless put us in the correct ballpark. Inserting this data into Eq.(1) yields a value of the attractive force of roughly 210 micro newtons (210×10^{-6}N). Prof. Autumn's article estimates that the gecko's toe has something on the order of 6.5×10^{6} setae which according to our calculation would give a maximum force of attachment of 1365 N. This is quite an impressive figure and Prof. Autumn points out that the gecko needs barely 0.04% of this maximum attachment load to support is weight under gravity. This is a very substantial margin of safety which is quite likely a good thing for the following reasons:

1. It is unlikely that the gecko will be able to bring all of the setae into intimate contact with any given surface at any given moment. The calculation reveals that just a few percent should be all that is required under normal circumstances.

2. The gecko must be able to adhere to a wide variety of surfaces which will all present different Hamaker constants to the spatulae. Again the wide margin of error will afford good contact under nearly all circumstances.

3. The gecko must further adjust for dynamical loads as it jumps around from leaf to stem and back and these loads can be many times the animals static weight.

Regarding the release mechanism, the gecko simply needs to flex the setae and thereby reorient them as shown in the release configuration in figure 1. Doing this effectively moves the contact distance to something on the order of the dimension of the spatula or roughly a micrometer or so. Note that the attractive force in Eq.(1) scales as the inverse third power of the gap distance. If we insert 1 micrometer into Eq.(1) instead of the intimate contact value the attractive force drops some 6 orders of magnitude to essentially nil.

Finally, Prof. Autumn did a clever experiment which illustrated the advantage of the ultra-hydrophobic nature of the spatula surface. He attempted to foil the gripping performance of the gecko's toe by contaminating it heavily with 2.5 micrometer glass microspheres. Initially the adhesion grip of the toe was substantially reduced but after a few steps it was found that the microspheres adhered much better to the substrate than to the setae and the effective attachment force rapidly recovered. Thus the gecko's toe has a rather nifty self-cleaning property due to the ultra-hydrophobicity.

I find all this truly amazing and quite ironic also. Here we are in the modern word with many of our best and brightest scientists and engineers in modern laboratories with multimillion dollar budgets trying to develop nanostructures for practical applications and here the lowly gecko has managed to develop just such a structure with no budget using wholly unskilled labor. The gecko has "out-nanoed" everyone without even trying. It sort of reminds me of the somewhat parallel situation in the field of "artificial intelligence". It is my recollection that we should have already had truly intelligent machines by the 1980's but in fact we are nowhere close. I always wondered what was the point of all the time, money and effort to create a truly intelligent machine when we currently put out the genuine article in roughly 9 months again using wholly unskilled labor? Rather than enter upon a pointless polemic I think it's a good idea to close here. For my part though I'm happy I don't have gecko's trying to invade my bird feeder.

BOOK REVIEWS

Interfacial Forces in Aqueous Media, Carel J. van Oss, (Marcel Dekker, Inc. New York 1994) 440 pages.

The previous issue of the newsletter reviewed the volume "**Applied Surface Thermodynamics**", A. W. Neumann and Jan K. Spelt, Eds. which evolved out of what I call the "Toronto School" of surface thermodynamics which has a strong leaning toward the continuum mechanics aspects of the subject as the editors hail from mechanical engineering departments. It is my distinct pleasure in this issue to review the counterpart to this volume by Prof. Carel van Oss who can be justly said to represent the "Buffalo School" of surface thermodynamics which has a distinct leaning toward applied chemistry and biochemistry. The volume consists of 21 chapters divided into three major sections labeled theory, experimental measurement methods and associated phenomena and applications.

This volume will definitely appeal more to those in Organic Chemistry, Biochemistry and Microbiology as the author hails from a Microbiology department and has intimate knowledge of the methods and concerns of those disciplines. The volume has much to recommend it from the point of view of organization and scope of coverage. Nearly every issue involving surface thermodynamics of concern to the biochemist or microbiologist is covered in some detail and the subject of contact angle measurement and interpretation is treated at length.

The book starts out with a discussion of the ever present London - van der Waals interactions and their contribution to the surface free energy of liquids and solids. A nice feature of this section is the compact treatment of Hamaker's relation as derived by the Lifshitz approach. This topic was treated in a cursory fashion in the previous issue of this newsletter and is one of the leading edge theoretical approaches to understanding how basic intermolecular interactions manifest themselves in the bulk thermodynamic properties of the surfaces which they comprise. Unfortunately the fundamental theory is quite formidable as it involves a quantum electrodynamic treatment of the interaction of radiation with matter. The author nonetheless presents the most salient results of this theory in a readily digestible form.

With the case of dispersion forces pretty much in hand the book then proceeds to cover the case of polar or acid-base interactions. Whereas there is a fair amount of agreement as to what is going on when only the classical dispersions forces are known to be active this is not the case when the more complex polar interactions raise their heads. The surface chemistry of the world would be fairly straight forward if only dispersion forces were active. In the first place there would be no life whatever on the planet which would eliminate nearly all the complication at a stroke. Fortunately for us however the polar forces are very much with us and though they keep us alive they concomitantly bedevil the surface theorists who attempt to account for their influence on the surface properties of material bodies. A brief look at the crux of the problem was hinted at in the previous issue of the newsletter. There we did an elementary quantum mechanical derivation of the interaction of two hydrogen atoms separated by a short distance which was nonetheless fairly large compared to the atomic size of hydrogen which is roughly the Bohr radius. Under these circumstances the interaction between the two atoms amounts essentially to that of two induced dipoles. The Hamiltonian of the system collapses to a fairly simple expression which can be treated by standard perturbation theory. The upshot is that one recovers the well known inverse sixth power dependence of the interaction energy on separation distance. Due to the assumed large separation of the two atoms, most of the complexity of the general interaction between the two atoms could be swept under the rug yielding a reasonably tractable problem. However, if the atoms are allowed to come within a few Bohr radii of each other then pandora's box really opens as a number of prickly complications come to the fore. First off we now have to take account of the internal degrees of freedom of the interacting electrons and protons. These are all Fermi particles which poses the immediate constraint that the total wavefunction must be antisymmetric under interchange of particles and the Pauli exclusion principle must also be observed. These matters can be handled in a fairly straightforward manner. However, the basic energy level structure of the two atoms also gets altered in a fundamental way which is not so straightforward. In particular we know that thermodynamically the two atoms would be happier as a hydrogen molecule than as two separate atoms and this interaction will in fact occur if enough kinetic energy is available so that a collision can effectively lift the electrons out of their ground states into a covalent bonding orbital. The formation of covalent bonds represents the strongest possible interaction for two atoms or molecules whereas the dispersion forces represent the weakest interaction. The polar or acid-base interactions fall into the grey area between these two extremes. Significantly stronger than the dispersion forces the polar interactions give rise to interactions such as hydrogen bonding in water which accounts for the exceedingly anomalous behavior of that liquid as compared to other fluids of comparable molecular weight. However, the polar interactions are not strong enough to give rise to permanent bonding which makes them all the more difficult to contend with.

The book deals with the problem of polar interactions essentially through the use of electron donor and electron acceptor concepts from classical chemistry. The contributions of the dispersion and polar forces are assumed to be additive and on this basis the semi-empirical van Oss, Chaudhury, Good theory of contact angle behavior is presented. Needless to say that given the complexity of the problem which this theory attempts to cover, it has not been entirely successful but it is nonetheless one of the first major efforts at attempting to bring some rhyme and reason to the problem. The reviewers own viewpoint is that an ultimate resolution for the problem will have to await an accurate and fully quantum mechanical treatment of the problem such as was provided by Lifshitz for the case of dispersion forces. As an undergraduate physics major I was obliged to take one year of Organic Chemistry as a graduation requirement. It was one of the burdens of attending a Liberal Arts School. At the end of the term I came away with the impression that all of Organic Chemistry was little more than a bag of tricks and stratagems to avoid having to do the quantum mechanics correctly. I more or less still hold to that opinion but I nonetheless realize that if we had to wait for the physicists to get around to working out the problems of Organic Chemistry via exact calculations there would be essentially no progress in the field and modern civilization would be denied much of the fruits of the chemical industry. Thus it is with the polar interactions, if we are to make any progress we will have to proceed incrementally via a succession of approximate theories.

Once we get by the polar interactions the book moves on to give a wealth of information on measurement methods and applications. There is far too much to treat in this short review but those readers from a biological and biochemical background will appreciate the final chapters on Cell and Particle Stability and Adsorption and Adhesion in Aqueous Media.

Apparent and Microscopic Contact Angles, J. Drelich, J. S. Laskowski and K. L. Mittal Eds. (VSP, Utrecht, 2000) 524 pages.

On the eve of the **FIFTH INTERNATIONAL SYMPOSIUM ON CONTACT ANGLE, WETTABILITY AND ADHESION** to be held in Toronto Canada this coming June, it is especially apropos to review this volume which contains some 28 papers taken from the International Symposium on Apparent and Microscopic Contact Angles held in conjunction with the American Chemical Society Meeting in Boston, August 24-27, 1998.

The volume is divided into 4 separate sections. Part 1 deals with nanoscopic and molecular effects on Contact angles. In part 2 the papers are focused on the perennial problem of surface forces and surface free energies which underlie nearly all the practical applications of contact angle work. Part 3 turns to the newer problem of contact angle behavior in the presence of surface roughness and surface heterogeneities. The papers in this section attempt of come to grips with the very practical but often vexing problem that in the real word almost no surface meets the ideal criteria assumed by the classic Young's equation. Finally the 4th and last section delves into the kinetic aspects of wetting and contact angle behavior.

The volume is well laid out and has the decided benefit of both subject and author indices which are becoming regrettably rare in proceedings volumes these days. Though there is insufficient space to cover the contents in much detail a few comments on will have to suffice to give the reader something of the flavor of what is presented. In part 1 in particular we find a most intriguing paper entitled "Measurement of Contact Line Tension by Analysis of the Three-Phase Boundary with Nanometer Resolution" by T. Pompe, A. Fery and S. Herminghaus. The novel feature of this work is that the authors have managed to apply Scanning Force Microscopy to obtain high resolution imaging of the three-phase contact line and the local liquid surface. This is a rather tricky technique but the authors were able to image the scalloped contact line with nanometer resolution putting this work most definitely on the frontier of contact angle work.

Moving on to part 2 we find two papers dealing with the classic problem of evaluating the surface free energy of solids from contact angle data. In the paper entitled "Determination of the Acid-Base Properties of Metal Oxide Films and of Polymers by Contact Angle Measurements" the authors E. McCafferty and J. P. Wightman present a classic example of applying the van Oss, Chaudhhury, Good theory toward the evaluation the surface free energy of oxide films and polymers. In a neighboring paper entitled "Acid-Base Surface Free Energies of Solids and the Definition of Scales in the Good-van Oss-Chaudhury Theory", C. Della Volpe and S. Siboni give a detailed presentation of the nuts and bolts of applying this theory in practical situations. In particular, attention is given to the numerical analysis involved in evaluating the set of coupled linear equations which arise due to the fact that at least 3 liquids must be used in order to pin down all the parameters of the theory. The classic example of this problem arises with the so called Hilbert matrix named after the famed mathematician David Hilbert. On the surface the Hilbert matrix looks quite demure but in fact it is devised in such a way that for any numerical machine operating with some finite level of numerical precision there is a Hilbert matrix that will utterly defeat nearly all numerical attempts at determining its inverse. The situation is devilishly deceptive in that a blind attempt to perform the inversion will give quite reasonable looking numbers which unfortunately turn out to be totally wrong. To further compound the problem, Hilbert matrices were not invented by malicious mathematicians setting out to trap the unwary but on the contrary arise quite naturally in the formulation of least squares analysis of linear systems. In their paper Della Volpe and Siboni are careful to take into account the condition numbers of their matrix data in order to eliminate at least one unwanted and unwholesome difficulty plaguing an already difficult problem.

In part three we come upon a number of papers dealing with curved and rough surfaces which might also be chemically heterogeneous. This type of work is quite valuable in that it brings contact angle work closer to the real life situations which those in industry and development laboratories have to deal with. A nice example is the paper by G. McHale, S. M. Rowan, M. I. Newton and N. A. Käb, "Estimation of Contact Angles on Fibers". The authors point out that a liquid that completely spreads on a flat high energy surface will give a measurable contact angle if the identical surface is turned into a cylinder. A theoretical treatment is given of the difficult to measure three phase contact line and experimental results are reported for poly(dimethylsiloxane) oils on a range of fiber surfaces. An interesting benefit of this work is that independent measurements of the inflection angle, droplet radius and the wetted length allow three estimates of the contact angle which provides a valuable consistency check on the measurements.

Finally in part 4 the problem of the kinetics of wetting is investigated. Five papers are presented all of which give interesting accounts of dynamic behavior ranging from evaporation effects to the influence of surfactants on the behavior of the triple line. The trickiest paper is the work of H. Haidara, L. Vonna and J. Schultz on "Surfactant Induced Wetting Singulatities in Confined Solid-Liquid-Liquid Systems: Kinetic and Dynamic Aspects". The experimental setup involves a devilishly subtle configuration whereby a drop is placed on an initially hydrophobic surface which has been made hydrophilic through the application of a monolayer. The dynamic behavior of the system is observed as a diffusing surfactant is slowly introduced which is attracted to the triple line. The resulting complex instability of the system is monitored as the surfactant interacts with the drop at the triple line. The resulting dynamics reveals the richness of the macroscopic behavior which can arise from subtle changes in the local molecular structures near the triple line.

VOLUME ANNOUNCEMENT

Adhesion Measurement Methods: Theory and Practice, Robert Lacombe (CRC, Taylor and Francis, Boca Raton, 2006)

It is our pleasure to announce here the availability of a newly published volume on ADHESION MEASUREMENT METHODS which arose out of the SHORT COURSE ON ADHESION MEASUREMENT METHODS which is given in conjunction with all of the MST symposia. Five years in the making this volume should be of interest to anyone who has to make applied adhesion measurements. A limited number of copies will be available at the registration desk during the upcoming June symposia at a 20% discount over the publishers price. Those taking the SHORT COURSE will get a copy at a 28% discount. A review of the book is out of the question here but a copy of the table of contents is attached to this issue of the newsletter for those who might have an interest.

UPCOMING SYMPOSIA

PRELIMINARY PROGRAM: TENTH INTERNATIONAL SYMPOSIUM ON PARTICLES ON SURFACES: DETECTION, ADHESION AND REMOVAL

This will be the tenth event in the series of symposia on particles on surfaces initiated as part of the Fine Particle Society meeting in 1986. Particles are yield detractors in the manufacture of sophisticated and sensitive electronic components and are very undesirable in many other technologies. Contamination of optical surfaces and shorting of microelectronic circuits by conducting particles, among other concerns, underscore the importance of particle detection, adhesion and removal. On the other hand, however, in certain instances particle adhesion to surfaces is necessary. The purpose of this symposium is to address the vast ramifications of particles on solid surfaces by bringing together specialists in many allied fields to discuss their latest findings and to identify areas for further investigation. Various types of substrates and particles including metals, oxides, glass, and polymers are covered. The following is a **partial** list of papers to be presented at the meeting. Please note that the address given may apply only to the presenting author

CLEANING TECHNOLOGY

Thomas Bahners, Helga Thomas and Eckhard Schollmeyer; Deutsches Textilforschungszentrum Nord-West e. V., Adlerstr. 1, 47798 Krefeld, GERMANY; **Electrospun Nanofibers - a Way to Improved Wet Filtration Efficiency of Textile Filter Media**

John Durkee; 437 Mack Hollimon, Kerrville, TX 78028; **500 New Cleaning Solvents Discovered!!**

Yakov Epshteyn, A. Scott Lawing and Jesse Federowicz; Rohm and Haas Electronic Materials CMP Inc., 3804 E. Watkins St., Phoenix, AZ 85032; **Ceria Slurry Particles Removal Optimization**

Katarzyna Haenni-Ciunel, Frank Schroeter, Torsten Textor and Eckhard Schollmeyer; German Textile Research Center North - West; Adlerstr. 1; D-47798 Krefeld, GERMANY; **Titanium Dioxide Nanoparticles in Photocatalytic Textile Applications**

Adam Judd, Timothy Fredette, Tania Alarcon, Sherry Kirkland, Gary Stickel, Daniel Heenan, Adam Kulczyk, and **Robert Kaiser**; Entropic Systems, Inc., P.O. Box 397, Winchester, MA 01890-0597; **Development of a Two Step Precision Cleaning Process for the Decontamination of Sensitive Equipment Items Contaminated with Chemical Warfare Agents**

Andreas Momber; RWTH Aachen, Faculty of Georesources and Materials Technology, Brunsstrasse 10, D - 21073 Hamburg, GERMANY; **Assessment Methods For Steel Substrate Cleanliness Prior to The Application of Organic Coatings - a Review of Practice Experience**

CLEANING MICROELECTRONIC AND OTHER STRUCTURES

Alex Kabansky; Cypress Semiconductor, San Jose CA, 95134; **Progress in Wafer Cleaning focusing on Particles, Residue and Defects for sub-100nm Silicon-based CMOS devices**

A. Lippert, P. Engesser, M. Köffler, F. Kumnig, R. Obweger, A. Pfeuffer and H. Okorn-Schmidt; SEZ AG, Research Center, Draubodenweg 29, 9500 Villach, AUSTRIA; **Keys to Advanced Single Wafer Cleaning**

Jin-Goo Park; Hanyang University, Div. of Materials and Chemical Engineering, Ansan, 426-791, KOREA; **The Effect of Chemicals on Adhesion and Removal of Slurry Particles During Cu CMP**

Stephen Silverman and Toufic Najia; Bartlett Bay Consulting,10 Stanhope Rd, So. Burlington, VT 05403; **The Flip-side of the Wafer: Backside Particles**

Craig M.V. Taylor, J. B. Rubin, A. Busnaina and L.D Sivils; Los Alamos National Laboratory, Mail Stop J-964, Los Alamos, NM 87545; **Precision Cleaning of Semi-conductor Surfaces using C_2 Bases Fluids**

A. S. Geller and **C. C. Walton**; Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550; **Improved Reticle Carrier Design Through Numerical Simulation**

PARTICLE DETECTION, MANIPULATION AND CONTROL

Peter X. Feng, P.Yang, Gerardo Morell, Ram Katiyar, and Brad. Weiner; Physics Department, University of Puerto Rico, San Juan, PR 00931; **Control of the Preferred Orientation of Nanoscale Carbon Particle Distributions**

Kenneth J. Ward, Milo Overbay and John W. Hellgeth, Hewlett-Packard Company, Corvallis, OR; **Chemical Identification of Submicron Size Organic Particles Using Conventional FTIR Microscopy: New Horizons for an Old Technique**

P.West and **N.Starostina**; PacificNanotechnology Inc., 17984 Sky Park Circle suite J, Irvine, CA 92614; **AFM Capabilities in Characterization of Particles: from Angstroms to Microns**

MICROBE AND BIOMOLECULE ADHESION

Niels P. Boks, Henny C. van der Mei, Willem Norde and Henk J. Busscher; Department of BioMedical Engineering, University Medical Center Groningen and University of Groningen, Antonius Deusinglaan 1, 9713 AV Groningen, THE NETHERLANDS; **Microbial Adhesion Forces Studied in a Parallel Plate Flow Chamber**

Astrid Roosjen; University of Wageningen, Laboratory of Physical Chemistry and Colloid Science, Dreijenplein 6, Wageningen 6703 HB , THE NETHERLANDS; **Adhesion, Prevention of Adhesion and Removal of Bacteria from Surfaces in Aqueous Environment**

Roel Irix-Speetjens, Wim Fyen, Jo De Boeck and Gustaaf Borghs; Department of Electrical Engineering (ESAT), Kuleuven, BELGIUM; **Study of the Effect of Surface Forces on the Mobility of Magnetic Particles in Biosensor Applications**

PARTICLE - SURFACE INTERACTIONS

F. Barbagini, W. Fyen, J. V. Hoeymissen, P. Mertens and J. Fransaer; U. Leuven, Dept. Metallurgy and Material Engineering, Kasteelpark Arenberg 44, 3001 Heverlee, BELGIUM; **Time-dependent Interaction Force Between a Silica Particle and a Flat Silica Surface in Dodecane**

R. Snel, **J. C. J. van der Donck**, J. H. van den Berg, H. Meiling and H. Meijer; TNO Science & Industry, P.O. box 155, 2600 JA Delft, THE NETHERLANDS; **Particle Detection on Flat Substrates**

Mahdi Farshchi-Tabrizi, **Michael Kappl** and Hans-Jürgen Butt; MPI for Polymer Research, Ackermannweg 10, 55128 Mainz, GERMANY; **Influence of Humidity on Adhesion: an AFM Study**

W. Wójcik , B. Jaczuk and R. Ogonowski; Department of Interfacial Phenomena, Faculty of Chemistry, Maria Curie-Skodowska University, Plac Marii Curie-Skodowskiej 3, 20-031 Lublin, POLAND; **Interaction of Silica Particles Through a Liquid**

PRELIMINARY PROGRAM: FIFTH INTERNATIONAL SYMPOSIUM ON CONTACT ANGLE, WETTABILITY AND ADHESION

In his opening remarks at the first symposium in this series Professor Robert Good pointed out that Galileo in the 17th century was quite likely the first investigator to observe contact angle behavior with his experiment of floating thin gold leaf on top of a water surface. Since that time contact angle measurements have found wide application as a method of determining energetics of surfaces. This, in turn, has a profound effect on the wettability and adhesion of liquids and coatings to surfaces. This symposium is concerned with both the fundamental and applied aspects of contact angle measurements. Issues such as the applicability and validity of various measurement techniques and the proper theoretical framework for the analysis of contact angle data will be of prime concern. In addition, a host of applications of the contact angle technique will be explored including but not limited to: wettability of powders, fibers, wood products, inks, paper, polymers and monolayers. Further focus will be on the use of contact angle data in evaluating surface modification procedures, determining relevance of wettability to adhesion, the role of wettability in bioadhesion, ophthalmology, prosthesis and in the control of dust in mining and milling applications. The primary focus of this symposium will be to provide a forum for the discussion of cutting edge advancements in the field and to review and consolidate the accomplishments which have been achieved thus far. Below is a **partial list** of papers which have been submitted. Please note that the address given may apply only to the presenting author.

CONTACT ANGLE BEHAVIOR IN PARTICLE, FIBER AND OTHER POROUS SYSTEMS SYSTEMS

Thomas Bahners, Lutz Prager and Eckhard Schollmeyer; **Functional Top Coats on Coated Textiles for Improved or Self-attained Cleanability**

Danielle Clausse; Dept. de Genie Chimique, Universite Technol. Compiegne, BP 649, F-60206 Compiegne Cedex, FRANCE; **Emulsions Stabilized by Nanoparticles**

B.P. Binks, **J.H. Clint**, P.D.I. Fletcher, T.J.G. Lees and P. Taylor; Surfactant & Colloid Group, Department of Chemistry, The University of Hull, Hull HU6 7RX, UK; **Effect of Surface Wettability on the Growth of Gold Nanoparticle Films**

Glen McHale, Michael I. Newton, Neil J. Shirtcliffe, F. Brian Pyatt and Stefan H. Doerr; **Self-organisation of Soil and Granular Surfaces**

L. Labajos-Broncano, M. J. Nuevo, M. L. González-Martín, J. A Antequera-Barroso and J. M. Bruque; Department of Physics, University of Extremadura, Campus Universitario, Avda. de Elvas s/n, 06071, Badajoz, SPAIN; **An Experimental Study about the Effect of the Interfacial Adsorption on the Imbibition of Aqueous Surfactant Solutions in Hydrophilic Porous Media**

A. Synytska, L. Ionov, S. Minko, K.-J. Eichhorn, M. Stamm and K. Grundke; Leibniz Institute of Polymer Research Dresden e.V., Hohe Str. 6, 01069 Dresden, GERMANY; **Model Structured Surfaces from Core-shell Particles. Influence of Chemical and Topographical Heterogeneities on Surface Wettability**

Po-zen Wong; Department of Physics, University of Massachusetts, Amherst, MA 01002; **Multilayer Adsorption on Fractal Surfaces**

Wen Zhong, Ning Pan and David Lukas; **Wetting and Adhesion in Fibrous Materials: Stochastic Modeling and Simulation**

CONTACT ANGLE, WETTABILITY AND ADHESION PERFORMANCE

Tanweer Ahsan; Henkel Corporation, 15350 Barranca Parkway, Irvine, CA 92688; **Adhesion Performance of Molding Compounds in Semiconductor Packaging**

C. Roero; High Voltage Laboratory, Swiss Federal Institute of Technology, CH-8092 Zürich, SWITZERLAND; **Long-term Stability of Hydrophilic Coatings on High Voltage Transmission Lines**

Frieder Mugele; University of Twente, PO Box 217, 7500 AE Enschede, THE NETHERLANDS; **Generation of Charge-Controlled Microdroplets Using AC-Electrowetting**

Juha Lindfors, Janne Laine and Per Stenius, Laboratory of Forest Products Chemistry, Helsinki University of Technology - TKK, FINLAND; **Adhesion of Hydrophobing Agents to Wet and Dry Surfaces**

Tao Du, Yazhen Wang, Peng Xia and **Yan Luo**; Research Center of Material Science and Engineering, Guilin University of Electronic Technology, Guilin, CHINA; **Study of ABS Resin Bond with Acrylonitrile-Modified Epoxy Resin**

CONTACT ANGLE AND WETTABILITY IN BIOLOGICAL SYSTEMS

Alain Carré and Valérie Lacarrière; Corning European Technology Centre, 7 bis avenue de Valvins, 77210 Avon, FRANCE; **Cell Adhesion and Proliferation on Polystyrene Substrates of Different Surface Properties**

A. Méndez-Vilas, M.G. Donoso, J.L. González-Carrasco, J.M. Bruque, **M. L. González-Martín**; Department of Physics, University of Extremadura, Campus Universitario, Avda. de Elvas s/n, 06071, Badajoz, SPAIN; **AFM Micro-Topography and Contact Angle Goniometry on Ti-Based Biomaterials**

M.L. González-Martín, A.M. Gallardo-Moreno, R. Calzado-Montero, J.M. Bruque, C. Pérez-Giraldo; Department of Physics, University of Extremadura, Campus Universitario, Avda. de Elvas s/n, 06071, Badajoz, SPAIN; **Physico-Chemisty of Initial Bacterial Adhesion. Insigts into the Relations Between Experiments and Model Proposals**

Mika M. Kohonen; Department of Applied Mathematics, Research School of Physical Sciences and Engineering, Australian National University, Canberra ACT 0200, AUSTRALIA; **The Effects of Wall Sculpturing, Sap Solutes, and Drying on the Wettability of Tree Capillaries**

Klaus Opwis, Thomas Bahners and Eckhard Schollmeyer; Deutsches Textilforschungszentrum Nord-West e. V., Adlerstr. 1, 47798 Krefeld, GERMANY; **Surface Modifications for the Control of Cell Growth on Textile Substrates**

Carel Jan van Oss; Department of Microbiology and Immunology; Department of Chemical and Biological Engineering, and Department of Geology; University at Buffalo, State University of New York, South Campus, Buffalo, NY 14214-3000; **Properties of Water in Colloidal and Biological Systems**

MEASUREMENT METHODS

Hossein Tavana and **A. Wilhelm Neumann**; Department of Mechanical Eng., University of Toronto, Toronto, Ontario M5S IA4, CANADA; **Contact Angles: Measurement and Interpretation**

M. G. Cabezas, M. Hoorfar, H. Tavana and A. W. Neumann; Escuela de Ingenierías Industriales, Universidad de Extremadura, ESPAÑA; **Axisymmetric Drop Shape Analysis (ADSA) for the Determination of Contact Angle**

M. J. Nuevo, L. Labajos-Broncano, M. L. González-Martín and J. M. Bruque Department of Physics, University of Extremadura, Campus Universitario, Avda. de Elvas s/n, 06071, Badajoz, SPAIN; **An Experimental Study about the Effect of the Velocity on the Contact Angle in Experiments of Spontaneous Flow of Liquids in Porous Media**

Dennis Palms, Rick Fabretto, Rossen Sedev, Joel De Coninck and John Ralston; Ian Wark Research Institute, University of South Australia, Mawson Lakes, SA 5095, AUSTRAILIA; **Measurement and Interpretation of Dynamic Contact Angles and Contact Angle Hysteresis**

Anselm Kuhn, and **John Durkee**; 437 Mack Hollimon, Kerrville, TX 78028; **Wettability Measurements for Surface Cleanliness Testing - an Old Technique Revisited & Updated**

P. J. Ramón-Torregrosa, M. A. Rodríguez-Valverde and **M. A. Cabrerizo-Vílchez;** Applied Physics Department, Sciences Faculty, University of Granada. E-18071 Granada, SPAIN; **Effect of Acid-Etching on Titanium Wettability. A Crossover Between Wetting Regimens**

Martien A. Cohen Stuart; Lab. of Physical Chemistry and Collloid Science, Wageningen University, P. O. Box 8038, 6700 EK Wageningen, THE NETHERLANDS; **Wettability of 'Soft' Surfaces: The Contact Angle on Swollen Polymer Brushes and Gels**

M. Brugnara, **C. Della Volpe**, G. Ischia, D. Maniglio, M.A. Rodrìguez-Valverde and S. Siboni; Dept. Of Materials Engineering, University of Trento, Via Mesiano 77,38050 Trento, ITALY; **Recent Advances in the Determination of an Equilibrium Contact Angle on Rough/Heterogeneous Surfaces**

M. Brugnara, M.A. Rodríguez-Valverde, S. Siboni and **C. Della Volpe**; Polymers and Composites Laboratory, Dept. of Materials Engineering and Industrial Technologies, University of Trento. E-38050 Trento, ITALY; **Comparison of Algebraic Algorithms for Drop Profile Fitting: Circle and Ellipse**

SUPER-HYDROPHOBIC EFFECT

A.Milne, W Li, K. Grundke and **A. Amirfazli**; Department of Mechanical Engineering, University of Alberta, Edmonton, AB, T6G 2G8, CANADA; **Wetting of Superhydrphobic Surfaces: Experimental and Theoretical Perspectives**

C. W. Extrand; Entegris Inc., 3500 Lyman Blvd., Chaska, MN 55318; **Modeling Ultralyophobicity: A Liquid Drop Suspended on a Single Asperity**

Emil Chibowski, Konrad Terpilowski and Lucyna Holysz; Department of Physical Chemistry-Interfacial Phenomena, Faculty of Chemistry,Maria Curie-Sklodowska University, Lublin, POLAND; **Superhydrophobic Effect Due to Deposition of Nano- and/or Microparticles on a Solid Surface**

Glen McHale, Michael I. Newton, Dale L. Herbertson, Neil J. Shirtcliffe and Stephen J. Elliott; School of Biomedical & Natural Sciences , Nottingham Trent University, Clifton Lane, Nottingham NG11 8NS, UK; **Electrowetting on Super-Hydrophobic Surfaces**

M. Ojha, S. Panchangam. P.C. Wayner, Jr. and **J.L. Plawsky**; Dept of Chemical and Biological Engineering, Rensselaer Polytechnic Institute, 110 Eighth St., Troy, NY 12180; **Effects of Surface Structure on Contact Line Behavior**

D. K. Sarkar and M. Farzaneh; Université du Québec à Chicoutimi, CANADA G7H 2B1; **Superhydrophobic Aluminum Surfaces**

N. Saleema, D. K. Sarkar, M. Farzaneh and E. Sacher; Canada Research Chair on Atmospheric Icing Engineering of Power Networks and Industrial Chair on Atmospheric Icing of Power Network Equipment, Université du Québec à Chicoutimi, CANADA G7H 2B1; **Effect of Temperature on Superhydrophobic Zinc Oxide Nanotowers**

A. Safaee, D. K. Sarkar and M. Farzaneh; Université du Québec à Chicoutimi, CANADA G7H 2B1; **Superhydrophobic Properties of Silver Coated Copper**

THEORY AND SIMULATIONS

Anton A. Darhuber, Nikolai V. Priezjev and Sandra M. Troian, Microfluidic Research & Engineering Laboratory, Princeton University, Princeton, NJ 08544-5263; **Slip Behavior at Liquid/Solid Interfaces: Hydrodynamic Predictions versus Molecular-Dynamics Simulations**

Hans Riegler; MPIKG, Am Mühlenberg, D-14476 Potsdam, GERMANY; **Wetting Properties, Interfacial Mobility and Aggregation Behaviour of Long Chain Alkanes at Solid/Vapour Interfaces**

Chiara Neto, Drew R. Evans, Christine L. Henry and Vince S.J. Craig; Department of Applied Mathematics, Research School of Physical Sciences and Engineering, Australian National University, Canberra A.C.T., AUSTRALIA; **Nanorheological Studies of Boundary Slip in Newtonian Liquids**

Thomas Luxbacher; Anton Paar GmbH, Anton-Paar-Strasse 20, A-8054 Graz, AUSTRIA; **Comparison Between Water Contact Angle and the Electrokinetic Characterization of Solid Surfaces**

Dandina N. Rao and Subhash C. Ayirala; The Craft & Hawkins Department of Petroleum Engineering, Louisiana State University, Baton Rouge, LA 70803-6417; **Mechanistic Modeling of Dynamic Vapor-Liquid Interfacial Tension in Complex Petroleum Fluids**

O. Karoussi and **A. A. Hamouda**; University of Stavanger, P. O. Box 8002 Ullandhaug, 4068 NORWAY; **The Effect of Binary Fatty Acids Systems on Partitioning, IFT and Wettability of Calcite Surfaces**

INVESTIGATIONS AT THE NANO-SCALE

Chuan Guo Ma; Min Zhi Rong and Ming Qiu Zhang; Materials Science Institute, Zhongshan University, Guangzhou 510275, P. R. CHINA; **Use of Wetting Coefficient plus Surface and Adhesive Work to Predict Dispersion State of Nano-$CaCO_3$ Fillers**

Thierry Ondarçuhu and Agnès Piednoir; Nanoscience group, CEMES-CNRS, 29 rue Jeanne Marvig, 31055 Toulouse, FRANCE; **Interaction of a Contact Line With Nanometric Steps**

A. Méndez-Vilas, A.B. Jódar-Reyes, M.G. Donoso, J.M. Bruque and M.L. González-Martín; Department of Physics, University of Extremadura, Campus Universitario, Avda. de Elvas s/n, 06071, Badajoz, SPAIN; **Nanoscale Exploration of Wetting/Dewetting Phenomena at Silicon Wafer Surface**

Aiping Fang, **Thierry Ondarçuhu**, Erik Dujardin, André Meister and Raphaël Pugin; Centre d'Elaboration des Matériaux et d'Etudes Structurales, CEMES-CNRS, 29 rue Jeanne Marvig, 31055 Toulouse cedex 4, FRANCE; **Nanoscale Dispensing of Droplets**

Jin-Goo Park; Hanyang University, Div. of Materials and Chemical Engineering, Ansan 426-791, KOREA; **Preparation and Characterization of Hydrophobic Anti-stiction Layer in Nano Imprinting**

APPLICATIONS TO SURFACE CLEANING AND COATINGS

Mariëlle Wouters; TNO Industrial Technology, Polymer Technology, De Rondom 1, Eindhoven 5612 AP, THE NETHERLANDS; **Aspects of Wettability and the Improvement of Adhesion of UV Curable Powdercoatings on Polypropylene Substrates**

S. Temmel, T. Höfler and W. Kern; Polymer Competence Center Leoben GmbH, A-8700 Leoben, AUSTRIA; **Surface Properties of Polymers Functionalized by UV Irradiation**

Ilker S. Bayer, **Constantine M. Megaridis**, Daniel R. Gamota and Jie Zhang; Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, Chicago, IL, 60607-7022; **Surface Free Energy Estimation and Wettability Characterization of UV Curable Coatings by Contact Angle Measurements**

R. N. Jagtap; University of Mumbai, Institute of Chemical Technology, N.M.Parekh Marg, Matunga, Mumbai 400 019 INDIA; **Stimulate of Contact Angle with Respect to Grafting of Butyl Acrylate Hybrid - Pud Adhesives for Plastic Laminates**

Laurence Boulangé-Petermann*, Christelle Gabet, Jean Charles Joud and Bernard Baroux; Ugine-ALZ, Arcelor, FRANCE (* Current address : Becton Dickinson, Pont de Claix, FRANCE); **Effect of the Surface Properties on the Cleanability of Bare and Coated Stainless Steels**

Emil Chibowski, Konrad Terpilowski and Lucyna Holysz; Department of Physical Chemistry-Interfacial Phenomena, Faculty of Chemistry,Maria Curie-Sklodowska University, Lublin, POLAND; **Influence of Ambient Humidity on the Apparent Surface Free Energy of Smooth Solid Surface**

SYMPOSIA INFORMATION AND REGISTRATION FORMS

DATES: JUNE 19-21, 2006: **FIFTH INTERNATIONAL SYMPOSIUM ON CONTACT ANGLE, WETTABILITY AND ADHESION**

JUNE 21-23, 2006: TENTH INTERNATIONAL SYMPOSIUM ON PARTICLES ON SURFACES: DETECTION ADHESION AND REMOVAL

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REGISTRATION: Speaker/student $395 each; regular attendee $595 each. A 20% discount applies if you are attending both symposia. An additional 10% discount applies if more than 1 person are participating from the same organization.

HOTEL: Please make room reservations directly with the Novotel Hotel. A block of rooms has been set aside for conference registrants until May 15, 2006. After this date the hotel will accept reservations on a space available basis and they cannot guarantee that the special conference rates of CAD$179 single/double per day will apply. Make your reservations early and be sure to mention that you are attending one of the MST symposia in order to receive the reduced conference hotel rate.

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SHORT COURSE ON APPLIED ADHESION MEASUREMENT METHODS, JUNE 24, 2006:
Associated with these symposia MST gives a short course on adhesion measurement methods. Since nearly all of the MST symposia have some relation to adhesion phenomena, the ability to quantify the adhesion of one material layer to another is clearly one of the unifying themes. This course is designed to mesh with the topical symposia by presenting an overview of the most useful adhesion measurement techniques which are being used to evaluate the **PRACTICAL ADHESION** of coatings. Emphasis will be given to methods which can be carried out in a manufacturing environment as well as in the lab and which give results that are directly relevant to the durability and performance of the coatings. The effects of material elastic properties and residual stress are considered as well as other external influences which affect coating adhesion.

Audience: Scientists and professional staff in R&D, manufacturing, processing, quality control/reliability involved with adhesion aspects of coatings or laminate structures.
Level: Beginner to Intermediate
Prerequisites: Elementary background In chemistry, physics or materials science.
Duration: 1 day
Registration fee: $595: Includes course notes, handouts and a copy of the newly published handbook and reference volume: **ADHESION MEASUREMENT METHODS: THEORY AND PRACTICE** (CRC Press, 2006).

How You Will Benefit From This Course:

- Understand advantages and disadvantages of a range of adhesion measurement techniques.
- Gain insight into mechanics of adhesion testing and the role of intrinsic stress and material properties
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CANCELLATIONS: Registration fees are refundable, subject to a 15% service charge, if cancellation is made by May 15, 2006. **NO** refunds will be given after that date. All cancellations must be in writing. Substitutions from the same organization may be made at any time without penalty. MST Conferences reserves the right to cancel any of the symposia or the short course if it deems this necessary and will, in such event, make a full refund of the registration fee. No liability is assumed by MST Conferences for changes in program content.

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