CAPCE Newsletter

Center for Advanced Polymer and Composite Engineering

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THE OHIO STATE UNIVERSITY

A National Science Foundation Industry/University Cooperative Research Center at The Ohio State University

New Members

The Masco Corporation is a new thrust area member in Thermoset Polymers and Composite Manufacturing. As one of the world's largest manufacturers of brand-name consumer products for the home and family, Masco is also a leading provider of services that includes the installation of insulation and other building products.

The Kimberly-Clark Corporation, a new thrust area member in Thermoplastic Processing, is a leading consumer products company. It produces many popular personal care, tissue and health care brands. Kimberly-Clark also is a major producer of premium papers. The company has manufacturing operations in 42 countries and sells its products in more than 150 companies.

Industrial Technology Research Institute (ITRI) is a government-sponsored, non-profit research organization in Taiwan. Mechanical Industry Research Laboratories (MIRL) is one of the major branches of ITRI. MIRL/ITRI will collaborate with CAPCE to develop new machines and processes for advanced polymer engineering, particularly in the field of microfabrication and BioMEMS.

INSIDE

CAPCE Phase II Award

CAPCE at The Ohio State University was launched on October 1, 1997, with a five-year Phase I award by the National Science Foundation (NSF). A five-year Phase II award for $365,000 will begin on October 1, 2002. Under the Phase II plan, CAPCE will expand to include two out-of-state institutional sites. NSF encourages the formation of multi-institution centers because they provide a broader research base that more readily addresses industry's research needs. One site is the Florida Advanced Center for Composites Technology at Florida A&M University-Florida State University (FAMU-FSU), lead by Dr. Ben Wang. The other is the Engineering Polymer Industrial Consortium of the Polymer Engineering Center (EPIC/PEC) at the University of Wisconsin-Madison (UWM), lead by Dr. Tim Osswald and Dr. Lih-Sheng Turng. Each site will bring additional industrial members and faculty researchers into CAPCE.

The FAMU-FSU site emphasizes study of the various life cycle issues regarding affordable composite materials, while the UWM-EPIC/PEC site advances the understanding and technology of a wide range of polymer and polymeric composite manufacturing processes. CAPCE projects that are proposed by the two new sites are listed to the right. For information, contact stevenson.2@osu.edu or 614-292-9271.

CAPCE Members

Bell Helicopter	Masco
Cinpres	Mattel/Fisher Price
CCP	METSS
Dow Chemical C&A	Moldflow
Dow Chemical PPG	Omnova Solutions
Dow Specialty Chem.	Owens Corning
Eastman Kodak	Plaskolite
Flexsys	PolyOne
Honda of America	Rheometric Scientific
ITRI	Siemens Automotive
Kimberly-Clark	Sumitomo
Instron Corporation	

FAMU-FSU SITE

- Science-Based Process Development of RTM and VARTM
- Permeability Characterization for Liquid Composite Molding
- Resin Infusion between Double Flexible Tooling
- Magnetically Aligned Nanotube Bucky Papers for Multi-Functional Composite Materials
- Molecular and Crystalline Characterization of Polyolefins and their Blends and Composites
- Development of Acoustic Attenuating Composites
- Development of High Temperature High Strength Rare Earth Al-based Alloys
- Rapid Cost Estimation for Early Composite Design Evaluation of Composites
- FRP Composites in Retrofit of Deficient Structures
- Modeling of Heterogeneity and Durability in Composites using Statistical and Neural Network Approaches

UWM–EPIC/PEC SITE

- Non-Invasive Visual Measurements of Polymer Processes
- Integration of Miniature Fusion Deposition Modeling and Laser Direct Write for Micro/Meso "Smart" Polymer Parts
- Microcellular Co-injection Molding
- Integration of Injection Molding Simulation and Optimization
- Research on Rheology in Plastics Processing
- Field-Aided Manufacturing of Polymer Composites
- Novel Sensor Technologies.

Feature Project

Processing and Cell Structure of Nano-Clay Modified Microcellular Foams

By Xiangmin Han and Changchun Zeng (Lee, Koelling, and Tomasko)

The addition of nanometer-sized particles can facilitate the formation of microcellular foams in the continuous extrusion foaming process. The nano-clay montmorillonite (MMT) offers a high aspect ratio (10-1000) and a high surface area. Both intercalated and exfoliated polystyrene/nano-clay composites were foamed using CO_2 as the foaming agent. Intercalation is the result of the penetration of polymer chains into the interlayer region and interlayer expansion. In intercalation the ordered layer structure is usually preserved and can be detected by X-ray diffraction. By contrast, in exfoliation the individual nanometer-thick silicate platelets are randomly dispersed in the polymer matrix. Exfoliation results in extensive polymer penetration and silicate crystallites delamination.

Microcellular foams are a novel material with many advantages. The nano-clay can facilitate the formation of small cells and change the cell structure (open or closed). The nano-clay can improve the properties of the resulting foams, such as the barrier properties, mechanical properties, and heat resistance. The adding of supercritical CO_2 may also help the dispersion of the nano-clay layers.

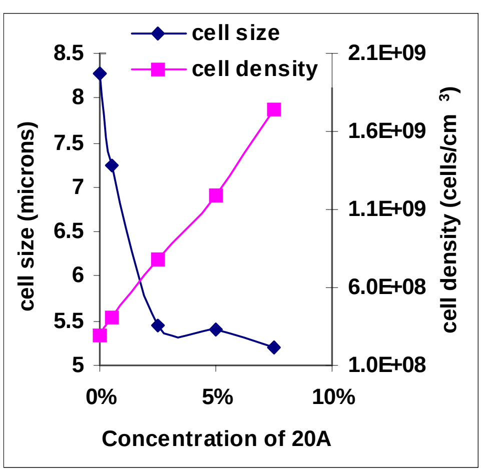

Figure 1. Cell size and cell density at different nano-clay concentrations for the PS/20A intercalated composites.

A polystyrene resin (Fina) was blended with Cloisite 20 A (Southern Clay) to make the intercalated structure in a twin-screw extruder (Leistritz ZSE-27). The exfoliated nano-clay/polystyrene compound was polymerized in-situ in our lab. The microcellular foaming extrusion was performed on a two-stage single-screw extruder (HAAKE Rheomex 252P).

As shown in Figure 1, the cell size decreased dramatically after a small amount of nano-clay (~ 2.5 wt%) was blended in polystyrene. The cell density increased nearly linearly with the increase of nano-clay concentration. Comparing the SEM images of samples containing 0%, 2.5%, 5%, and 7.5% 20A, it was found that an open cell structure is created at high nano-clay concentrations. TEM results showed that many small cells nucleate around the nano-clay particles and grow along the length direction of the clay to form cigar-shape foams. We also compared the nucleation effect with talc, which indicated that the nano-clay has a higher nucleation ability.

As a comparison, an exfoliated polystyrene/nano-clay composite was prepared

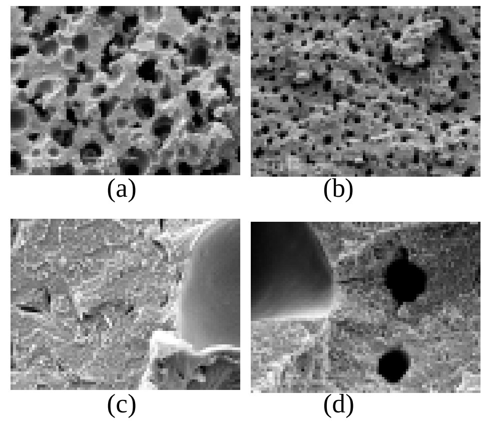

Figure 2. SEM images of intercalated and exfoliated composite foams at different magnifications: a) intercalated ($\times$800); b) exfoliated ($\times$800); c) intercalated ($\times$12800); and d) exfoliated ($\times$12800).

by in-situ polymerization and then foamed at 200 ^{0}C. The foamed exfoliated composite extrudate exhibits a very smooth, glossy surface that may come from the orderly alignment of the single clay layers, or from less flaws due to a strong dispersion of the clay particles in the polymer matrix. Instead of open cells as observed in the intercalated sample (Figure 2a), the SEM picture (Figure 2b) of the exfoliated composite shows a microcellular foam structure in which cells are round in shape and well separated from each other. Very few coalesced cells are observed. The calculated average cell size and cell density are 4.9 microns and 1.5×10^9 cells /cm^3 respectively. Figures 2c and 2d show the SEM pictures at a higher magnification for intercalated and exfoliated composites, respectively. The intercalated nanocomposite foams exhibit a bimodal cell size distribution, with larger cells about 5 microns in diameter and smaller cells less than 1 micron distributed on the cell wall. The exfoliated nanocomposite foams also show that finer features exist on the cell wall. However, from the SEM it is unclear whether these features are small bubbles at the nanometer scale, or the nano-clay layers themselves. Further study is being conducted in this area to better understand the effects of particle size, dispersion and concentration on the foam structure and properties.

High Shear Rheometer

By Kai Kang (Koelling, Lee)

A conventional rheometer can only achieve shear rates as high as 10^3 s^{-1}. In this study, a micro-channel type structure is used to obtain shear rates as high as 5 x 10^6 s^{-1}. Its micro size (~ 1 µm) offers a high surface-to-volume ratio, allowing a high mass and heat transfer rate; a high shear/extension; and a low Reynolds number. A series of polymer solutions were tested in this unit, using a 1%, 1.5% and 2% 4,000,000 Mw polyethylene oxide (PEO) solution. The data obtained from this new rheometer extend conventional rheometer results smoothly. At an extremely high shear rate, polymer degradation is observed. It was found that this degradation is controlled by shear stress, rather than shear rate.

High shear rheology is required in many situations. One example is in lubricant development. This micro-channel rheometer can also be used in the blood viscosity study in capillary blood vessels. Common rheometers tend to treat red blood as a homogenous fluid. Given the relative sizes of red blood to capillary blood vessels, this is an inappropriate treatment. A micro-channel type rheometer, however, has an intrinsic similarity with such a system. Thus it is an important tool for studying material transport in microfluidic devices.

Co-injection Molding of Thermoplastic Foam Materials

By Shunahshep Shukla (Koelling)

A Hele-Shaw Cell has been set up in our lab to study the interfacial evolution and viscous fingering characteristics of two-phase liquid-liquid systems. Combinations of liquids with different rheological properties are being studied in our simplistic Hele-Shaw geometry to gain some insight into the instability characteristics of the interface in an actual mold cavity. Another goal in this research is to look more closely into the currently held theories of nucleation in polymeric foam systems and generate and examine experimental data to better understand the phenomenon.

The shear viscosity of molten polystyrene foams at low shear rates was measured earlier on a parallel-plate rheometer (RMS-800) available in our lab. Experiments are planned to measure the viscosity of polystyrene foam and gas charged polymer solutions at high shear rates using a capillary die attached downstream of an extrusion system. Other experiments are planned that will optimize key processing parameters in the machine in order to produce lightweight plastic parts having excellent surface finish and good mechanical integrity.

Simulation of Injection Molding with Micro-Features

By Liyong Yu (Lee, Koelling)

Simulations for injection molding with micro-features were conducted using Moldflow software. The studied mold cavity is a thin-wall rectangular plate with a microchannel (W/H=200µm/1000µm) in the midplane. The model employed a high variety of mesh densities. Both 2D X-Y midplane and 3D simulations were conducted. 2D simulation showed that the micro-feature deterred the main flow, while 3D simulation showed no obvious effect on the main flow. Both 2D and 3D simulations obtained a similar filling depth in the micro-channel. Simulation in the 2D X-Z plane was also developed, and the results were close when using a high heat transfer coefficient. However, it also shows that the filling depth is very sensitive to the heat transfer coefficient. Efforts are underway to study the effects of inertia and fountain flow.

Rheology and Processing of Polymeric Coatings

By Jianhua Xu (Koelling)

The rheological behavior of waterborne paints is being studied. It was found that these paints exhibit shear thinning behavior, as well as thixotropy. The current treatment of paint as a Newtonian fluid is not satisfactory when used to calculate the pressure drop in the paint circulation system. Our study showed that although the paint exhibited thixotropy, a pseudo steady-state flow would exist shortly after the start of circulation. At the pseudo steady-state, the Carreau model can be used to predict the pressure drop satisfactorily over a fairly wide range of flow rates. At lower flow rates, the power law model is also adequate. In addition, the degradation of the paint caused by circulation is also being studied. The tiny metallic flakes in the paint will "crumple" under high shear rate so that the final paint film will look "dull", which is unacceptable. The high shear rate occurs at the pump and the back-pressure regulator in the circulation system. A series of experiments with different settings of the back-pressure and flow rate is being performed. We hope to be able to figure out optimum operating conditions, i.e., the back-pressure setting and flow rate, which will reduce the amount of degradation and energy used to maintain the circulation.

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Effect of Non-Newtonian Rheological Properties on the Gas-Assisted Injection Process

By Yijie Wang (Koelling)

Gas-assisted injection molding is a newly developed technique in the polymer processing field. Stainless steel capillary tubes with different diameters were used as the flow geometry. Three types of Carbopol solutions with highly shear thinning rheological properties were tested as the displaced fluids. Two different concentrations were tried to study the effect of shear thinning on the thickness of the coating layer left on the inner wall after the bubble penetrated through the tube. The results showed that for fluid with a small Power Law index *n* (i.e., the fluid is strongly shear thinning), deviation of the fractional coverage *m* from the result obtained using Newtonian fluid was larger than the fluid with larger *n*. Also for strongly shear thinning fluid, a difference in the tube diameter would make the plots of *m* vs. Ca obtained in different tubes scattered from each other and no master curve was formed. For fluid with *n* larger than 0.34, the effect of tube diameter was negligible. Future work will involve finding a new definition of Ca that best represents the flow field. A frozen layer model will predict the change of *m* as a function of Ca.

Interfacial Tension between Supercritical CO_2 and Molten Polystyrene

By Hongbo Li (Tomasko and Lee)

The interfacial tension between the SCF CO_2 (Supercritical CO_2) and polymer melts is very important for understanding the SCF CO_2 assisted processes, such as blending, coating, and forming. However, due to the high pressure and temperature, no data is available. In our current work, a high pressure, high temperature view cell has been set up and the ADSA (axisymmetric drop shape analysis) was used to determine the interfacial tension between the SCF CO_2 and PS (polystyrene). The interfacial tension was investigated at two temperatures (T=228°C and T=198°C) in the pressure range 1~103 atm. A linear dependence of interfacial tension on the pressure was observed. For T=228°C the interfacial tension between SCF CO_2 and PS decreases from 27.54 dyn/cm to 17.07 dyn/cm as pressure increases from 1 atm to 103 atm. For T=198°C, the same trend of interface tension reduction was observed.

Dynamics of Structure Evolution of Binary Polymer Systems under Simple Shear Flow

By Yong Yang (Lee, Koelling)

Binary polymer blends with well-defined initial structure were prepared by Computer Numerically Controlled (CNC) machining, photolithography and microembossing. The size and distribution of the dispersed phase and the composition of the blends were designed using these methods. Compatibilizer can also be easily placed at the interface of the two components during sample preparation. Using the micro-fabricated samples, the dynamics of phase inversion and the morphology evolution of binary polymer blends were studied in simple shear flow under isothermal conditions. With well-defined samples, blend rheology becomes very sensitive to structure changes. The presence of compatibilizer strongly affects rheological response during blending, which can be explained by interfacial tension and phase inversion. The effects of interfacial tension, viscosity ratio, blend composition, and shear rate on rheology and morphology evolution in polymer blending are being investigated.

Bonding and Surface Modification of Polymer Microdevices

By Siyi Lai and Yeny Hudiono (Lee)

Various approaches for polymer-based microfabrication have been established in our lab in recent years. However, bonding (i.e., sealing the microfluidic platform with a lid) and surface modification (e.g., hydrophilicity, protein adsorption) are still challenging issues in the fabrication of polymer microdevices. Recently we have developed a new method, resin-gas injection, for bonding and surface modification of polymer-based microfluidic platforms. This new approach can easily seal microfluidic devices with micron and sub-micron sized channels without blocking the flow path. It can also be used to modify the channel shape, size and surface characeristics. By applying the masking technique, local modification of the channel surface can be achieved through cascade resin-gas injection. Therefore, microfluidic functions such as capillary valving can be realized. Experiments are underway to demonstrate how surface modification affects fluid flow, mixing, sampling, and protein adsorption in microfluidic chips.

Preparation and Properties of Polymer Nanocomposites

By Changchun Zeng (Lee, Lannutti and Walter)

Poly(methyl methacryalte)(PMMA) and polystyrene (PS) nanocomposites were prepared via melt intercalation as well as in-situ polymerization. The nanoparticles used were clay and nanoporous silica. Using a reactive surfactant to modify the clay surface,

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Feature Project

Predicting Molding Forces During Sheet Molding Compound (SMC) Compression Molding

By Lisa M. Abrams (Castro)

Sheet Molding Compound (SMC) consists of thermosetting, polyester resin, particulate filler, and fiber reinforcement. SMC is increasing in popularity in the plastics industry due to its high strength-to-weight ratio, corrosion resistance, and low cost. One of the fastest growing applications of SMC compression molding is the manufacture of truck body panels. Due to their large size, the molding forces developed are substantial and have a major influence in the molding cycle. As SMC moves towards parts requiring higher strength, the glass composition of the SMC increases. This requires larger molding forces, and thus predicting them becomes more critical.

When molding a part with a press of a given capacity, it is helpful to be able to determine the range of feasible closing speeds. The faster the press can close, the shorter the fill time. If the fill time is decreased, a more reactive SMC composition can be used, thereby reducing the cure time. Controlling the speed of the press is also key in optimizing the surface properties of a finished part, accurately estimating manufacturing costs, and producing parts in a consistent, repeatable manner. Knowing the speed of the press, the molder can calculate the fill time and thus more accurately estimate manufacturing costs. For smooth plant operation, it is crucial to have repeatability and consistency in molding conditions and surface properties.

In this research, a model relating molding force, compression speed, and part thickness to material properties, part size, and processing conditions was developed, in order to predict and optimize the filling time and overall cycle time. The model was then experimentally verified using commercially-made parts.

To develop useful models of SMC flow, one needs to start with experimental facts because SMC is a complicated material. Relying on a detailed microscopic description of the flow and using only continuum mechanics arguments would lead to unsuccessful efforts. The flow behavior of SMC during compression molding results from its fiber mat structure, coupled with actual process conditions. Conventional SMC contains 25 percent by weight, one-inch (25.4 mm) long glass rovings that are randomly oriented in the plane of the sheet. The chopped rovings strongly reinforce the paste matrix of the SMC, resulting in the macroscopic observation that SMC flows like a plug. This means that the velocity in the direction of the flow is independent of the direction of the thickness of the SMC.

When the SMC at room temperature is placed on a hot mold (300 degree F/149 degree C), the surface of the SMC softens. This softened, resin-rich surface acts as a lubricating layer. Thus, for the purposes of modeling, the flow field can be divided into two regions: the core, which occupies most of the flow domain; and a thin lubricating layer. This is shown schematically in Figure 1. Consequently, SMC thins out mostly by extension. The resistance to extension adds to the surface friction in opposing the flow. Assuming the SMC paste in the lubricating layer can be represented by a power law

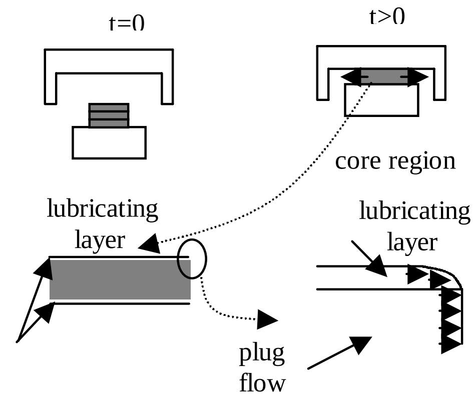

Figure 1. Modeling the Flow Field.

model and the thickness averaged stress in the core can be represented as a linear function of the planar rate of deformation tensor, the expression relating the instantaneous force (F_L) to the closing speed (U) and instantaneous gap (h) is:

$$F_L = \frac{4\eta UV}{h^2} + \frac{2mU^nV^{n+2}}{\delta^n W^{n+1} h^{2n+3}(n+2)}$$

where F_L notes that the charge is located on the far left of the mold, η represents the material resistance to extension, V is the volume which remains constant in compression molding, m is the power law consistency index, n is the power law index, δ is the thickness of the lubricating layer, and W is the mold width. If the flow is still one-dimensional but can proceed in two directions (that is, the charge is located in the mold center instead of one side), then F and V are replaced by $F/2$ and $V/2$ respectively in the above equation, giving a reduced molding force (F_C):

$$F_c = \frac{4\eta UV}{h^2} + \frac{2mU^nV^{n+2}}{\delta^n W^{n+1} h^{2n+3} 2^{n+1}(n+2)}$$

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A method was developed to measure the material parameters using flat plate moldings. Figure 2 (right) shows a comparison of predicted versus experimentally-measured forces for a typical automotive SMC, in which the charge is located in the center and left of the mold. Commercial SMC moldings are very close to one-dimensional flow. This is especially true for the later part of the filling stage where the required force is the largest. Thus, these equations can be used for typical commercial exterior body panels.

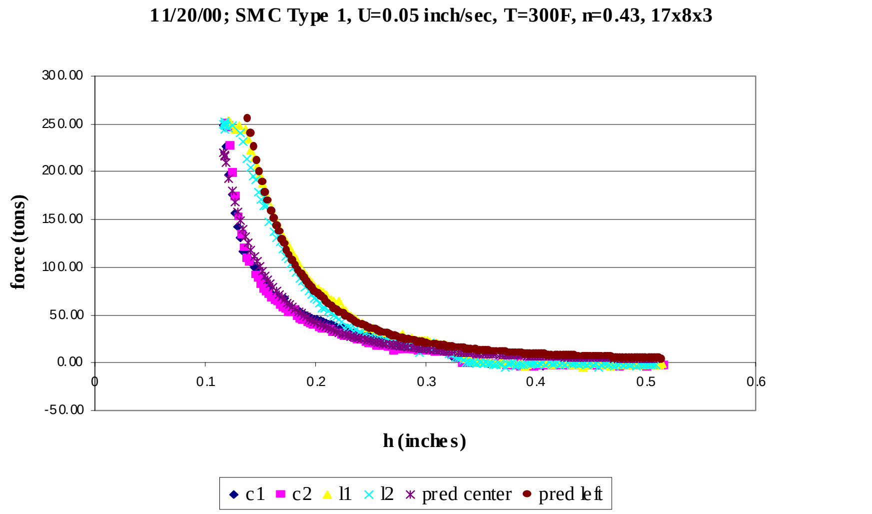

Figure 2. Predictions vs. experimentally-measured forces for typical auto SMC.

Shrinkage Control and Styrene Residue of Unsaturated Polyester (UP) and Vinylester(VE) Resin Systems Cured at Low Temperatures *By Xia Cao (Lee)*

In low temperature molding processes, shrinkage control and residual styrene are important concerns. The presence of low profile additives (LPA) can reduce the shrinkage of unsaturated polyester (UP)/ styrene (St) resins cured at low temperatures under proper processing conditions, but may affect the residual styrene content. A systematic study was carried out to investigate the effect of reaction temperature, initiator systems, and modification of the resin system on structure evolution, final resin conversion, and shrinkage control of UP resins with LPA. When cured isothermally at low temperature, the addition of the comonomer MMA, along with a dual initiator, can increase resin conversion. Adding MMA has a positive effect on the final conversion, but a negative effect on shrinkage control of UP/St/ LPA systems because the resin system/ LPA is more compatible with the addition of MMA (i.e., less phase separation). The detailed mechanism is still unclear and needs further study. Different LPA contents in the UP/St/LPA system with MMA will be chosen to study the phase separation and volume shrinkage compensation. This effort will be expanded to cover vinylester resins.

Compression Molding of Epoxy Pre-Pregs *By Gang Zhou and Shengnian Wang (Lee)*

An Instron 8500 press simulator was used to carry out the compression molding of epoxy pre-pregs in a closed cavity of varying thickness. The pressure and displacement profiles as well as the temperature distributions in the mold were measured. The process of fiber buckling during compression was recorded by a digital camcorder onto DV tapes. A series of compression tests was completed. Preliminary analysis of the test results indicates that the optimum cure processing conditions for the epoxy coupons are a high mold temperature and a low pressure application rate. Other test variables do not appear to be as critical. A statistical analysis of all test variables will be applied to explain the observed phenomena and to optimize the molding process. In future research, nano-clays will be added into epoxy resins, and pre-pregs will be prepared by this epoxy composite. The effects of nano-clays on reaction kinetics and rheological changes of epoxy resin will be determined. The final product is expected to possess better mechanical and thermal properties. Finally, the optimal conditions of sample preparation and processing are determined to achieve the best properties of the hybrid composites.

Novel UV Curing Technology for Gel Coats and Thermoset Composites *By Liqun Xu (Lee)*

In recent years, UV curing has been introduced to process gel coats and thermoset composites due to the increasing demand for reducing the emission of Volatile Organic Compounds (VOC) during composite processing. The UV curing of gel coats and composites is more complicated than conventional thin-film UV coating, because of light scattering and absorbing by pigments and other components (e.g. glass fiber, resin, etc.) and the use of a photoinitiator. A dual curing system consisting of a thermal initiator and a UV initiator is a very promising method to fully cure the pigmented thick gel coats or composites. The UV initiator can cure the surface resin rapidly, while the thermal initiator can be activated by UV reaction exotherm to cure the inside portions of the gel coats or composites.

A thorough understanding of the photocure reaction mechanism is necessary for choosing the appropriate initiating wavelength, type of photo and thermal initiators, and composition of unsaturated polyester (UP) resins. A study of the kinetics and rheology of dual curing of gel coat and composite resins is being conducted by means of differential photocalorimetry (DPC) and rheometry.

The resulting kinetic and rheological data and models, together with a heat transfer model will be used in numerical analysis of composite processing. We plan to study the effects of processing parameters, like initiator concentration and formulation, light intensity, temperature, and UV exposure time on mechanical properties of the gel coats and composites. Other important physical properties will also be compared with thermally cured and UV cured products, such as gel coat surface quality, water resistance, and adhesion of gel coat to the composite surface of thermal/ultraviolet cured samples.

Pultrusion Experiments and Solventless Prepregs for Electronic Application

By Permadi and Liqun Xu (Castro, Lee)

As part of the pultrusion project, a set of pultrusion trials was carried out at Dow's Freeport Laboratory to determine the highest line speed without "blister" formation for a 90×9mm profile with 101.6cm (40inch) length die using a Dow vinylester resin. These experimental results can be used to determine the relationship between the limiting pultrusion speed and die length or profile thickness.

Based on the concept of Resin Injection Pultrusion (RIP), a continuous solventless approach for producing prepregs is being developed in our laboratory. Instead of dipping the reinforcing material into a resin and solvent bath in an open pan, the glass fabric is impregnated by injecting resin in a closed die. This process can eliminate the conventional process drawbacks (e.g., environmentally unfriendly and high possibility of void formation). The previous two efforts have characterized the potential resin and proven that the pulling and the flow inside the die are feasible. Currently, a pilot facility for solventless electronic prepregs has been developed. The die and the injection part have been built and tested. It was confirmed that the pilot facility can be used for future experiments. A simulation with a simple exothermic model is being developed to predict the flow and heat transfer inside the die. It will determine the proper temperature and pulling speed of the process in order to avoid residual resin build-up inside the die.

Sheet Molding Compound

By Sarah Boyland (Castro)

Several different fiber lengths and fiber types were used in Sheet Molding Compound (SMC) in order to determine the effect that these would have on the surface quality, force to mold, and the physical properties of the SMC. All moldings were conducted so that the flow was one-dimensional. Therefore, the physical properties were tested both perpendicular and parallel to the direction of the flow in order to determine the differences in strength. In addition, continuing the research of Lisa Abrams, several steps were outlined to help characterize the SMC. The characterization can then enable an engineer to predict the force needed to mold a part. The mathematical model developed by Abrams was programmed into a Matlab code. If the force available to mold a given part is known, then the user can determine the speed at which the press will close and the fill time.

Optimization Studies in Reactive In-Mold Coating

By Mauricio Cabrera-Rios (Castro)

In-mold coating (IMC) products have been applied for many years to reinforced plastics, and recently to thermoplastic parts to enhance the surface. IMC provides a smooth, sealed surface, useful as a conductive or nonconductive primer for subsequent painting operations. Painting is, however, an expensive and non-environmentally friendly operation. Therefore, there are important incentives to use IMC as a topcoat, i.e., as in-mold paint. Acceptance of IMC as a competitor to the traditional painting processes will depend upon the improvement of its ability to satisfactorily meet two key performance objectives: high quality of the final surface and short cycle time. The goal of this research work is to develop optimization strategies to find solutions that are optimal for a single performance measure, or the best compromises for multiple performance measures in the IMC process. To achieve this goal we are exploring the use of Artificial Neural Networks as metamodeling techniques and the use of Data Envelopment Analysis for multiobjective optimization.

Numerical Simulation of 2D In-Mold Coating Flow

By Xu Chen (Castro)

Computer code was developed for in-mold coating of thermoplastic materials for simple geometries. The results were verified by experiments. Our current study is on the numerical simulation of the IMC flow for more complicated geometry. A key issue is including the rate of change of the control volume caused by the compressibility of the thermoplastic substrate. The compressibility of the thermoplastic substrate is taken into account by introducing the P-V-T relationship of the substrate into the code.

Experimental Studies on IMC of Thermoplastic Substrates

By Konstantin Zuyev (Castro)

A pilot facility was set up for in-mold coating of thermoplastic substrates. The facility includes a 50-ton Sumitomo injection molding machine, a mold with attached heating elements, a 6-stage temperature controller, an in-mold coating unit, an injection nozzle, and a pressure/temperature sensor. The objectives of the experiments are to investigate the influence of substrate thickness on coating adhesion; collect pressure/temperature data during injection molding of the in-mold coating cycle; and to predict that data and establish a process window. ■

Next IAB Meeting

The next CAPCE Technical Review and Industry Advisory Board meeting will be held at the Holiday Inn on the Lane in Columbus, Ohio, on *Tuesday and Wednesday, April 23 and 24, 2002*. For more information contact (614) 292-9271 or stevenson.2@osu.edu.

New CAPCE Reports

Available to industry members

A-01-07 "Rheology and Processing of Automotive Polymeric Coatings," by Susan Porter and Kurt Koelling.

A-02-01 "Experimental and Numerical Analysis of Micro-injection Molding," by Liyong Yu, L. James Lee and Kurt Koelling.

A-02-02 "Dynamics of Structure Evolution of Binary Polymer Systems under Simple Shear Flow," by Yong Yang, L. James Lee and Kurt Koelling.

A-02-03 "Interfacial Tension between Supercritical CO2 and Molten Polystyrene," by Hongbo Li, David Tomasko, and L. James Lee.

T-01-09 "Development of Process Conditions and Cycle Time Estimation for a New Solventless Process to Manufacture Prepregs and Copper Clad Laminates for Printed Circuit Boards," by Permadi and Jose Castro.

T-02-01 "Effect of Secondary Monomer and Curing Agents on Shrinkage Control and Residual Styrene of Unsaturated Polyester Resins Cured at Low Temperatures," by Xia Cao and L. J. Lee.

T-02-02 "Effect of Resin Rheology on Fiber Deformation in Prepreg Compression Molding," by Gang Zhou and L. James Lee.

T-02-03 "Morphology and Mechanical Properties of PMMA/Organoclay Nanocomposites" by Changchun Zeng, L. James Lee and John J. Lannutti.

T-02-04 "Bonding and Surface Modification of Polymer Microdevices," by Siyi Lai, Yeny Hudiono and L. James Lee.

T-02-05 "Processing Studies in Sheet Molding Compound Compression Molding," by Lisa M. Abrams and Jose Castro.

T-02-06 "Effective Mass Diffusivity in Composites," by Shoujie Li, L. James Lee and Jose Castro.

T-02-07 "Processing Studies in Sheet Molding Compounds (SMC) Compression Molding," by Lisa Abrams and Jose Castro.

Equipment Update

The Bohlin stress rheometer Model USO-120 and the Instron MicroTester Model 5848 have been installed. Final negotiations are underway with the supplier to purchase a co-injection molding machine with foam molding capabilities.

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exfoliation can be achieved in both PMMA and PS matrices by in-situ polymerization. The fracture behavior of clay and nanoporous silica-based PS nanocomposites was studied in-situ. It was observed that crack propagation during fracturing is different for PS nanocomposites with different clay dispersions. PS nanoporous silica showed quite different fracture behavior from PS clay nanocomposites. The thermal stability and flame resistance of nanocomposites were also studied. It was shown that adding a small amount of clay greatly reduced the peak heat release rate during burning. However, the flame resistance as well as the thermal stability of nanocomposites seemed to depend on the clay dispersion. We are currently studying the relationship between surfactant thermal stability, clay dispersion in the shear flow field and the resulting thermal stability and flame resistance of the nanocomposites.

For more information contact CAPCE at 614-292-9271 or stevenson.2@osu.edu.
Director - Dr. L. James Lee
Associate Directors - Dr. Kurt W. Koelling and Dr. Anthony F. Luscher
Administrator - Dr. Paula J. Stevenson

Center for Advanced Polymer and
Composite Engineering
The Ohio State University
125A Koffolt Laboratories
140 W. 19th Avenue
Columbus, OH 43210-1180

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