Re-Certification Workbook

for renewal of CCT credentials

v. 2.0 - 2005

CCT Re-Certification

In the ongoing process of keeping abreast of developments in the the composites industry, Certified Composites Technicians must re-certify their credentials on a three year cycle. The CCT Re-Certification Workbook is a self-study course designed to facilitate the revalidation of your CCT credentials. The articles presented in the workbook include a review of selected CCT information; an introduction to composites processing technologies not discussed in the original study guide; and information on selected plant safety issues. Successful completion of the workbook test is the basis for renewal of your CCT credentials.

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Section 1

Defining Composites

What are thermoset composites?

What are composites? As elementary as the question may seem to those in the "composites" business, the exact definition of composites is somewhat elusive.

In the convolutions of the English language the term "composite" is used in a number of contexts. For example, there is the field of *composite photography*, where two or more photographs are joined to form a single image. The Air Force operates *composite wings*, which are units made up of various types of aircraft. Botanists speak of *compositae*, a plant family that includes dandelions. Mathematicians define a *composite number* as an integer exactly divisible by at least one number other than itself. And then of course there are *composite materials*.

The term composite is derived from the Latin *compositus*, stemming from the root word *componere*, to bring together.[1] This accurately describes the application that puts together materials to form a composite.

Defining composites as an engineering material requires a progressive definition, which begins with the general and moves to the specific. The broad general definition of a composite is: *"Two or more dissimilar materials which when combined are stronger than the individual materials"*[2]

This definition draws attention to the synergistic effects of combining materials that have different properties, to create a new material with superior properties to the individual components. This definition can apply to both natural and synthetic (manmade) composites: Wood is an example of a natural composite that falls into the broadest definition of composites. Wood is a combination of cellulose fiber and lignin. The cellulose fiber provides strength and the lignin is the "glue" that bonds and stabilizes the fiber.

Manmade composites can be constructed using natural materials. Adobe bricks are a perfect example of a composite material; the combination of mud and straw forms a material that is stronger than either the mud or the straw.

There are many forms of synthetic composites. Steel and concrete combine to create structures that are strong and rigid. In this case the synergy results from the high stiffness and compression strength of the concrete, and the high tensile strength of steel, creating a structure that is strong and stiff. A very different composite is automobile tires. A steel belted radial tire uses rubber as a strong but flexible matrix to encapsulate steel strands which have high tensile strength.

This broad definition however, is too general to describe the specialized form of materials from which the composites industry takes its name. A definition is required that adequately segregates these structural materials from other engineering materials. Brent Strong uses this definition in his book, "Fundamentals of Composites Manufacturing" - *The combination of a reinforcement material (such as a particle or fiber) in a matrix or binder material.*[3] Dr. Strong points out, "That the term composite also implies that the materials are macroscopically identifiable, that is, the materials are not merely different at the molecular level but have distinctive component properties and they are generally mechanically separable. This definition excludes many materials, which might have been included in the broader definition such as: metal alloys, plastic copolymers, minerals, glasses, and wood.”

Defining Thermoset Composites

Broad General Definition:
“Two or more dissimilar materials which when combined are stronger than the individual materials.”

This definition includes a wide range of materials combinations, such as; wood, adobe bricks, steel and concrete, rubber and steel (tires), concrete, and of course the combination of polymer resins and fibers.

Intermediate Definition:
“The combination of a reinforcement material in a matrix or binder material.”

This more focused definition narrows the range of materials to a reinforcement and a matrix. In this case reinforcements could include fibers or particles, and the matrix may be a polymer resin, ceramic, or metal. Examples include: metal and ceramic matrix materials, reinforced thermoplastics, and reinforced thermoset polymer resins.

Precise Definition:
“Composites are a combination of a reinforcement fiber in a thermoset polymer resin matrix, where the reinforcement has an aspect ratio that enables the transfer of loads between fibers, and the fibers are chemically bonded to the resin matrix.”

The precise definition of thermoset composites as an engineering material is based on the physical property characteristics of these materials. The synergy created by load transfer between fibers, and the chemical bonding of the reinforcement to the matrix, are the defining terms of this description.

To hone a finer edge, the definition must be developed to the next level. One must examine the engineering properties of the component materials that form a composite. Considering that a composite is a combination of reinforcement in a matrix, it becomes necessary to define the terms *reinforcement* and *matrix.*

In engineering terms, one of the functions of a reinforcement in a composite is to take up the load strain transferred through the matrix. The load must then be distributed throughout the matrix and reinforcements.

Particles generally have a low aspect ratio (a comparison of length to width) and are roughly spherical in shape. Generally referred to as *fillers*, particles consist of both organic and inorganic materials. The most common particles found in plastic materials are, calcium carbonate (limestone), calcium sulfate, and alumina trihydrate. Additionally, hollow and solid spheres of glass or other materials may be used as fillers.

Particles in a matrix (such as a resin) produce isotropic properties. That is, the material will have the same tensile, compression and elongation properties in the X, Y and Z-axis. In other words, a particle filled matrix will be homogenous (the same throughout), as are metals. Particles however, are *not* effective as reinforcements. By virtue of having low aspect geometry (rough spherical shapes), they do not effectively transfer loads from particle to particle, and they produce a homogenous structure. *Therefore, particles are not considered, or referred to, as reinforcements in composites materials.*

Fibers are reinforcements, having one long axis compared and one short axis. – a high aspect ratio. In the matrix, fibers overlap to a degree that strain within the matrix is transferred to a series of fibers. Where fibers overlap, the load is distributed to adjacent reinforcements, with the matrix holding the fibers in place and transferring the strain from fiber to fiber. By nature of having a high aspect ratio (long and narrow), fibers may be oriented in a specific direction and have the capability to produce a material with aniso-tropic properties; a material that is stronger in one direction than the other. Fibers can be used to produce a non-homogeneous structure, which has different properties in different directions. This is a distinct advantage in an engineering material.

The function of the matrix in a composite is to provide a relatively rigid media that is capable of transferring loads to the fiber components of the material. The matrix encapsulates the reinforcement creating the physical properties synergy between the two materials. In forming “composites” a critical aspect in the amalgamation of the matrix and the reinforcement is that a chemical bond is formed between matrix and the reinforcement.

To explore this concept further, consider the combination of a thermoplastic resin (such as polypropylene) and glass fiber; in this case the reinforcement fiber is merely encapsulated by the resin matrix but not molecularly bonded to the resin. Whereas, the combination of glass fiber and thermoset polyester resin produces a chemical bond at the interface of the fiber and the resin. Therefore, we arrive at one of the distinctive characteristics of a composite engineering material – the reinforcement is not merely encapsulated by the matrix, but is molecularly bonded to the matrix. The bonding of reinforcement and matrix produces the superior physical properties, chemical resistance and fatigue endurance, which characterize composite materials.

Now, having the technical aspects of composites characterization in hand, the definition of these materials can move to the final step of refinement.

> "Composites are a combination of a reinforcement fiber in a polymer resin matrix, where the reinforcement has an aspect ratio that enables the transfer of loads between fibers, and the fibers are chemically bonded to the resin matrix." [4]

This precise definition accounts for the attributes of thermoset composites as an engineering material, and differentiates them from a host of *combined* materials having lesser degrees of synergy between the individual components.

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Section 2

Open Molding Laminating Techniques

A review of the fundamental techniques

The fundamental process of open molding is creating a composite laminate. Across the wide range of types of open molded products, materials and techniques, the common denominator of the industry is applying resin saturated fiber reinforcement to the face of a mold. While this methodology is as old as the industry, and the most simplistic of all composites technology, it is the most important open molding fundamental to both understand and teach within your operation.

The integrity of a molded composite part is dependent on the quality of the laminate. Proper laminating techniques are the foundation for quality FRP production. By following correct laminating procedures, you will insure product design requirements are met. In addition, finished product cosmetics will be enhanced and expensive rework will be kept to a minimum.

Within the open molding process there are two methods of laminate application – Hand Lay-up and Spray-Up. These names are derived from the method of applying the fiberglass reinforcement and are not related to the resin application method.

Hand lay-up involves the use of roll-stock fiberglass reinforcements such as chopped strand mat, woven roving, knitted fabrics or textile fabrics. The glass fiber is positioned in the mold and then resin is applied to wet-out the material. In hand lay-up, resin can be applied in several different ways:

1) Resin can be applied using the bucket and brush method, where the resin is mixed in a container and manually distributed across the laminate. This is termed *hand lay-up - manual process.*

2) Resin can be applied with a spray gun. This is termed *hand lay-up – mechanical process*.

3) Resin can be applied with non-spray equipment, such as a flow applicator or a pressure fed roller. This is also known as *hand lay-up – mechanical process*.

Spray-up involves the use of a chopper gun. The chopper gun pulls continuous strand roving (also known as gun roving) through a chopper unit. The fiberglass roving is cut into short lengths and merged into a resin stream that is deposited on the mold. The chopper gun mixes the resin, initiator, and glass, while the operator controls the laminate application. There are two types of chopper equipment:

1) Spray guns - which atomize the resin stream.

2) Flow choppers - which create a non-atomized resin fan pattern. (Flow choppers include multiple orifice fluid tips and impingement fluid tips.)

Objectives of Open Molding Laminating

It is important to understand the specific objectives of the FRP laminating process when teaching the fundamentals. The purpose of the FRP laminating process is to:

- Properly place or distribute the glass reinforcement on the mold.
- Saturate the fiberglass reinforcement with the right amount of resin.
- Remove entrapped air and compact the laminate.
- Achieve the proper glass to resin ratio.
- Properly cure the laminate.

Placement of Reinforcement

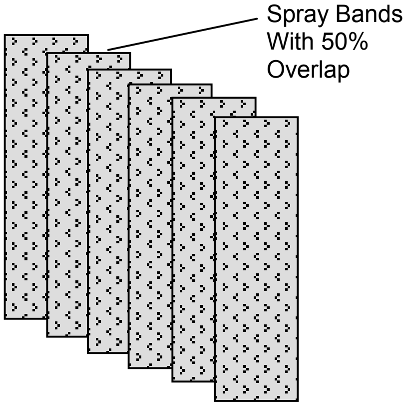
An important aspect of hand lay-up is the proper location of overlaps and seams. It is typical that several pieces of fiberglass reinforcement must be joined, for example in corners, or across large areas. The seams should have a specific location, and overlaps should have a minimum overlap distance. This insures the structural properties of the laminate will be satisfactory. When dealing with thick laminates, it is desirable to *stagger* overlaps, to avoid over-thick build-ups in the overlap area.

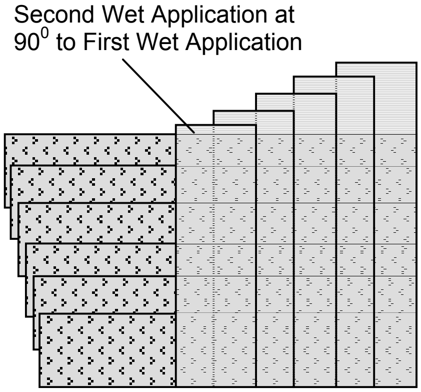
Spray-Up (Chopping)

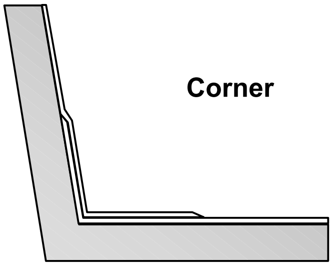
In the chopping process, the placement of the glass reinforcement across the mold is a function of the set-up of the spray gun and the operator's ability to dispense the chop across the mold surface.

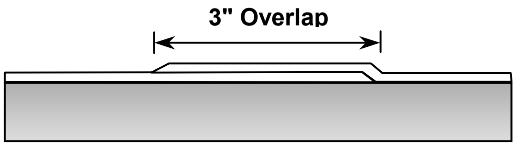
Chop Distribution in the Spray Pattern
Achieving a uniform glass distribution across the spray pattern involves several adjustments to the spray equipment:

1. The fluid tip must produce a spray pattern suitable for the size and shape of mold to be sprayed. A spray fan pattern that is either too wide or too narrow, will lead to poor distribution of glass across the pattern.









2. The chop chute must be positioned to cause the glass to enter the resin stream at the proper distance from the spray gun. When the chopper unit is aimed "high", the chopped strands merge with the spray pattern further downstream and in the center of the pattern. When the chopper is

aimed “low”, the chop merges close to the gun in the narrow portion of the spray pattern. This can cause chop to fall off the sides of the spray pattern. The chute must be positioned so the chopped fiber impinges evenly across the resin stream.

3. The chopper speed and the resin exit velocity must be correlated. If the velocity of the chop exiting the chute is too high it will blow through and around the sides the spray pattern. If the exit velocity is too low, the chop will tend to “clump” in the center of the pattern.

Chop Thickness

The operator controls the laminate thickness in the chopping process. This involves time and motion. The speed at which the operator moves the gun over the surface will determine how much material is deposited in a given area. Once adjusted, the chopper gun puts out a fixed amount of chop; if the operator moves the gun faster the chop will be thinner, and if the movement is slower the chop will be thicker. A chopper gun operator must move the gun at a constant speed to produce a consistent laminate thickness.

Spray Bands

Spray bands refer to the pattern of spraying chop across a mold surface. Each “run” of chop across the mold should be overlap the previous run by 50%. In addition, chop should never be applied in one direction. Always, spray a portion of the total thickness in one direction and a portion at 90^0 to the first direction. This promotes an even distribution of laminate across the mold surface.

Glass to resin Ratio

Glass to resin ratio is simply the amount of resin in a laminate, compared to the amount of glass fiber. In open molding applications, this measurement is typically determined by the weight. For example, if a laminate uses 1 lb. of glass fiber and 3 lbs. of resin – the total weight of the laminate is 4 lbs. The weight of the glass is 25% of the total laminate weight. The proper terminology to describe this is: “The glass content is 25%, or the glass to resin ratio is 25:75.”

There is a “right” amount of resin for a specific amount of glass. The proper amount of resin is important to the quality of the product and will affect the structural properties of the laminate. The condition of too much resin is termed resin rich and not enough resin is known as resin starved.

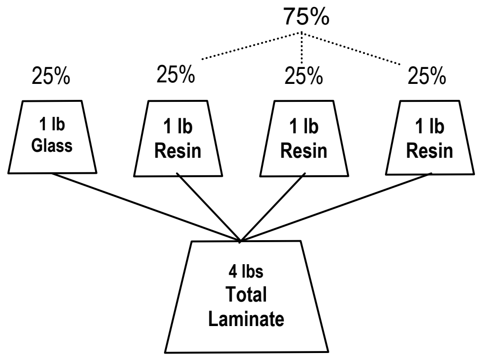
Deviations from the specified glass to resin ratio in a laminate will affect structural properties, laminate weight, part cosmetics, cost, and emissions.

Achieving the proper glass to resin ratio is very important to the quality of the product. The laminate has been designed with a certain percentage of resin and glass, to provide the required physical properties. If there is a deviation from the specified glass to resin ratio, the strength of the laminate will change.

How Can Too Much Resin Cause Weak Parts?

It doesn’t seem to make sense - if you add more resin to a laminate, the structure will become weaker. Shouldn’t more be better? The fact is, the more resin added to a laminate, the lower the strength. The key to understanding why using too much resin can make a laminate weaker is that compared to glass fiber, polyester resin is a brittle material.

A casting of resin with no glass fiber will have



25% Glass Content – 75% Resin Content

lower flexural strength compared to the same sample reinforced with glass fiber. More fiber in the resin matrix, by proportion, decreases the amount of brittle material in the laminate; whereas more resin in the laminate increases the amount of brittle material in the laminate by proportion.

Adding excess resin to a laminate (causing resin richness), changes the proportion of glass to resin fiber. As the amount of resin increases, the laminate becomes more brittle.

If adding excess resin causes the laminate to become thicker, the stiffness of the laminate might actually increase, but because of the increase in brittleness, the overall strength may decrease. There is a difference between stiffness and strength.

To understand the difference between stiffness and strength, consider the comparison of a piece of typical window glass and a sheet of thick rubber. The window glass has high stiffness – but low strength. The sheet of rubber has low stiffness – but high strength. A laminate with excess resin becomes more like the window glass – stiff, but easy to break.

Determining Glass to Resin Ratio

There are several methods to determine the glass to resin ratio in a laminate:

1) Visually, the primary means during the laminating process.

2) By accurately measuring both the resin and glass during the laminating process.

3) By using a laboratory procedure called an ignition test or a burn-out test.

During the laminating process the primary means to determine glass to resin ratio is *visual.* It is surprisingly easy to be reasonably accurate in determining actual glass content by simply looking at the laminate. For both training purposes and on-going quality control, three sample laminates should be available, one that is resin rich, one resin starved and one at the proper ratio.

By comparing the look of the surface of the three samples it is easy to determine if excess resin is present or if the glass is not fully saturated. A laminate with the proper amount of resin should have a dull surface appearance with a distinct fiber pattern showing. If the surface has a “wet gloss” and individual fibers cannot be seen, it is resin rich. If the fiber has the “whitish” appearance with transparent, air filled areas, it is resin starved.

Saturation of Fiberglass Reinforcement

In the laminating process, *saturation* is to wet-out individual glass filaments within the reinforcement, and to fill the area between reinforcement fibers with resin. There are a number of factors related to saturating glass fiber with resin. These include:

- Resin type and formulation
- Resin monomer content
- Resin viscosity
- Temperature
- Glass reinforcement type
- Glass to resin ratio
- Available time

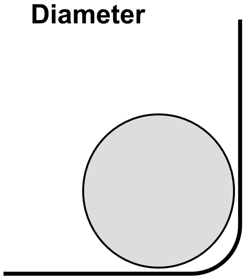
Each of the above factors will influence the amount of time and effort it takes to completely wet-out a laminate. Generally speaking, the higher the resin viscosity and the thicker the reinforcement, the slower the laminate will wet-out and the more work it will take to saturate the glass fiber.

Air Removal and Laminate Consolidation

When the fiberglass reinforcement is saturated with resin, air voids are trapped within the laminate. Air voids (air bubbles) that remain in the cured laminate can cause a range of problems, from cosmetic defects to structural failures. In addition, the laminate must be *compacted* on the mold surface and particularly in corner areas. The technical term for compacting is *laminate consolidation.*

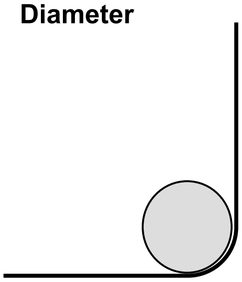
The working concept of removing air bubbles is not to push the bubbles around in the laminate, and not primarily to “pop” the bubble. The concept is to consolidate the laminate, so there is no room left for air voids. In other words, the goal is to push the saturated glass reinforcement uniformly down to the mold surface, causing air voids to be squeezed out of the laminate. Various laminating tools are used to saturate, consolidate, and eliminate air voids from the laminate.

Wrong Roller Diameter



Resin Rich Corner

Right Roller Diameter



Properly Compacted Corner

This process requires various laminating tools, some of which work in conjunction with particular types of reinforcement materials. These include; FRP rollers, brush rollers, paint brushes, paint rollers and squeegees. There are two categories of laminating tools: Tools Used to Compact the Laminate; Tools Used to Modify Resin Content.

A standard serrated FRP roller is good at compacting the laminate, but is not effective in removing excess resin. On the other hand, a paint-roller or a paintbrush are excellent tools with which to add or remove resin to the laminate, but not particularly effective in compacting.

The key to effective laminating is to always use a compaction tool along with a resin content modification tool. In other words, always use one tool to remove air and another to move resin. In most cases, laminating is a “two handed sport” – a roller in one hand and a paintbrush in the other. One tool is used to remove air and compact the glass, and the other tool to remove excess resin and work the corners.

Tools of the Trade

FRP Roller – Used to promote saturation of the glass reinforcement, to compact the laminate and to remove air voids. This tool is not very effective in distributing resin, or in adding or subtracting required resin to a specific area. It is important to note that the size of the FRP roller must match the shape of the mold. When rolling relatively flat areas, larger surfaces require rollers of larger diameter and width. When rolling radii, the diameter of the roller should match the corner radius. Using a roller larger than the radius corner produces a resin rich corner. Every laminating operation should have a wide range of rollers with various diameters and widths available for different mold configurations.

Brush Roller – Is particularly effective for rolling chopped strand mat pre-lays (skin coats). This tool will assist with the removal of “micro-air” from behind the gel coat. The brush roller tends to be less effective on thicker bulk laminates, and does not work well on chopped laminates due to picking-up strands of chop. Brush rollers are generally used to create high quality skin coats.

Squeegee – The classic “Thalco” squeegee is the tool of choice for processing textile fabrics, such as 6 oz. or 10 oz. cloth. In hand lay-up, the squeegee is used to both the distribute resin and consolidate the laminate. A skilled laminator simultaneously pouring a stream of resin across a fabric while following with a squeegee represents a high level of craftsmanship in laminating. Following the *pour*, a serpentine squeegee motion, using just the right pressure, produces a perfectly uniform laminate surface of a precise glass to resin ratio.

Paintbrush – An essential laminating tool that is used to work radii and remove excess resin. A paintbrush should always be used in conjunction with an FRP roller. It is observed that the most competent experienced laminators work with an FRP roller in one hand and a paintbrush in the other.

Paint Roller – A standard 9" paint roller is a highly effective tool for both distributing resin and removing excess resin from a finished laminate. The paint roller is used to follow-up the FRP roller, and creates a uniform surface resin content and professional looking high quality laminate.

Understanding the simple and basic concepts of open mold laminating, and using the proper tools are prerequisites for producing quality laminates. Ongoing training of operators is essential in the quest for production consistency and laminating success.

Section 3

Understanding Polyester Resin Curing

Effective handling of resin in the shop

The chemical reaction of crosslinking is the fundamental process of producing composites products. The work of converting a liquid polyester or vinyl ester resin into a solid is termed curing, and the mechanism by which curing occurs is crosslinking, or addition polymerization. Understanding the crosslinking reaction for polyester resins can make a significant difference in procedures used in laminating or gel coating, and in the quality of your products.

Polyester resins consist of a polymer (a long chain molecule) and a crosslinking agent, usually styrene. Styrene not only works in the crosslinking role, but also lowers the viscosity of the polyester polymer to provide a workable product. Picture a series of tennis balls connected in a string. The molecular chains are independent and possibly mechanically intertwined but other wise unconnected; this is resin in the liquid state.

The crosslinking reaction begins with the addition of a curing agent known as an initiator. The common initiators used in open molding are sometimes erroneously called a catalyst. However, technically a catalyst starts a reaction but is not consumed in the process. An initiator enters into the reaction and is consumed; *therefore MEKP and BPO are actually initiators and not catalysts as commonly termed.*

The initiator (an organic peroxide), produces free radical molecules. These free radicals open the bonding sites on the polyester chain molecule. Imagine the tennis balls on a string as molecules. The initiator causes a tennis ball in the molecular chain to be covered with Velcro of the loop variety. The bonding sites on the styrene molecules are also opened, so we also have a styrene "tennis ball" covered with Velcro of the hook variety. The bridging step in the reaction takes place when the Velcro tennis balls touch to form a bond. The bond between the polyester molecule and the styrene molecule actually produces a new free radical molecule (another Velcro covered tennis ball) that is available to open a new bonding site and keep the reaction going.

The result of the molecular bridging or bonding is a network of interconnected polyester polymers with the styrene molecules serving as the links between the chains. Resin converting from a liquid to a solid is the result of this *crosslinking* or addition polymerization.

The crosslinking reaction is at maximum activity from the time the initiator is introduced to the resin to the time of peak exotherm. As the molecular matrix proceeds to interconnect, the crosslinking activity slows down as the conversion proceeds to a solid. In the beginning of the reaction there are many molecules available for bonding and they are very mobile in the liquid state. However as the reaction progresses, and the crosslinking density increases, there are less available bonding sites and the molecules are less mobile.

How does this affect the practical aspects of curing a resin or gel coat in a production setting? A vast majority of crosslinking takes place in the early stages of the curing process from the addition of the initiator to peak exotherm. As the cure progresses, a geometrically smaller number of reactions take place. The molecular chains are bound in the increasingly solid matrix and there are fewer opportunities for contact with a free radical molecule. By the time peak exotherm occurs, only a small number of bonding sites are available and the reaction declines rapidly.

On the practical level, this is what you need to know about polyester resin curing **-** It is important to get a good crosslinking reaction up front during the early stages of the curing process; that is from the time of the addition of initiator to the time of resin peak exotherm. If an inefficient reaction occurs in the initial stages of cure, it is difficult to remedy the problem at a later time.

What causes a poor initial crosslinking reaction? Low initiator levels are always suspected; improper amounts of promoter or inhibitor in the resin; and low shop temperature all contribute to poor cure. Assuming the proper initiator is being used, all resins and gel coats have a minimum specified level of initiator. Any amount less will not provide a sufficient quantity of free radicals to fully crosslink the resin. If the levels of promoter or inhibitor additives in the resin are out of balance a sluggish cure may result. Low ambient air temperature is one of the most common and overlooked problems associated with poor cure. Because the crosslinking reaction is very dependent on temperature, conditions below 60^0 F present a potential curing problem. A thin laminate or gel coat film may also contribute to a sluggish cure. Other common problems such as poor catalyst mixing or water in the plant air system will contribute to improper curing.

In many cases, fabricators attempt to compensate for a poor "up front" cure with questionable methods. One is the mistaken idea that given enough time laminates will fully cure. This has bred the fiberglass folklore that laminates never stop curing, or it takes two months, or two years to get a complete cure. This is incorrect. Very little crosslinking takes place in a solid resin matrix. What is sometimes perceived as a continuing cure, over a period of time, is usually unreacted styrene being released from the resin matrix. Eliminating these "loose" styrene molecules may cause some shrinkage in the laminate and sometimes can be identified by styrene odor if the laminate is in a confined area. However, additional curing (that is crosslinking) is not taking place.

The same holds true for post curing at elevated temperatures. If two unreacted bonding sites are in intimate contact, a crosslink may occur if the temperature is elevated. However, for the most part, "post curing" does not cause further curing, but rather either eliminates unreacted styrene from the resin matrix, or links styrene to styrene, which is not a desirable result.

So what does all this mean? The significance of this discussion is that it is important to get the proper cure *up front*, and that it is ineffective to attempt to compensate for a poor cure with remedial action. Allowing the laminate to dwell longer in the mold, or post curing at elevated temperature, does not compensate for the initial problem. Many composite quality problems are a direct result of a faulty cure. These problems are best addressed by implementing proper production procedures. For example, use the proper initiator in the proper ratio; maintain shop temperatures above 60 degrees F at all times; pay attention to details such as catalyst mixture, compressed air quality, and application techniques.

In warm weather do not drop initiator levels below the minimum specified percentage. If gel times are too fast at the minimum initiator level, the solution is to extend the resin gel time with the help of the resin supplier. Do not use so called “half strength initiators” or “summer catalyst” without increasing the initiator percentage to correspond to the minimum active oxygen level of standard initiator; using these products can result in permanent undercure may occur even in the hottest weather.

Understanding the concept of creating a high crosslinking density in the initial stages of curing will contribute to quality laminates. Make free radicals work for you. The molecule you crosslink today will be one less molecular delinquent to deal with tomorrow.

Section 4

Reference Guide to RTM and VIP

A Comparison of pressure vs. vacuum processing

The resin transfer molding (RTM) process and vacuum infusion processing (VIP) were initially developed nearly five decades ago. Until recently, these molding methods either languished in the background of mainstream molding, or experiencing sporadic interest from the composites community. Today, both processes are receiving well-deserved attention with the development of highly engineered systems.

RTM and VIP are most often associated with intermediate or low volume closed mold processing, and are generally considered the step up from open molding. While the terms "resin transfer" and "vacuum infusion" are sometimes used interchangeably, the methods are very different.

There has been some of the confusion created concerning these molding processes with the use of proprietary names and acronyms. Many molders have developed a minor processing distinctive, and have coined a unique name to describe their version of the generic process. In the course of developing these process variations, commercial names and the associated acronyms have been attached to particular methods. In some cases, the terminology incorrectly describes the process.

From a technical perspective, the terminology is straightforward: If the pressure in the mold cavity is higher than atmospheric pressure - the process is Resin Transfer Molding (RTM). If the pressure in the mold cavity is lower than atmospheric pressure - it is Vacuum Infusion Processing (VIP). Think of it this way - If a pressure pump provides the motive force to the resin, the process is RTM. If a vacuum pump provides the motive force in moving resin into the mold cavity, the process is VIP.

There are hybrid variations of each process. For example if vacuum is used in conjunction with resin injection, the process can be termed "vacuum assisted resin transfer molding" or VARTM. If the mold cavity pressure is higher than atmospheric pressure, VARTM is a variation of RTM, and not a fundamentally different process. It is possible to inject resin into a vacuum bag at a pressure lower than the vacuum applied to the mold cavity. If the overall pressure in the bag is lower than atmospheric pressure (negative pressure), the process is a variation of vacuum infusion.

The developments in vacuum infusion processing during the last decade involve advances in introducing resin into the vacuum bag. The use of well designed resin distribution manifold systems and the introduction of flow media in the vacuum bag has allowed greater control over the transport of resin into the bag. Additionally, the use of a flow media on the laminate surface allows faster and more efficient reinforcement saturation. VIP is drawing current interest because of low capital investment, easily manageable learning curve, and potential emissions reductions.

Resin transfer molding has received much recent attention with the development of RTM based manufacturing systems. The basic molding process has been augmented with automated handling and sophisticated process control systems. Process control enhancements maximize the efficiency of resin mixing, injection, and curing aspects of the process. In addition to computer-based process control, advancements in RTM tooling have been introduced with VEC™ system floating mold concept, and the Plastec™ multiple insert tooling system. Both of these new tooling methods address previous issues of tool cost and process efficiency. RTM has advanced from the "low-cost-closed-molding" stage to a highly engineered process with substantial manufacturing capabilities.

Both RTM and VIP present specific attributes which characterize the capabilities of the molding methods:

RTM - VIP Reference Guide

	Resin Transfer Molding	Vacuum Infusion Processing
Tooling	Requires a two-sided mold set. Molds must be designed and engineered to accept clamping and resist hydraulic pressure within the mold cavity. Injection ports and vents must be strategically located. Heated tooling is required for serious RTM production. Building successful tooling requires specific RTM toolmaking experience.	VIP tooling can be virtually identical to a standard single-sided open molds. An adequate perimeter flange is required to mount the vacuum bag. Thin "hard shell" molds can be used in lieu of a vacuum bag. Building tooling requires no special expertise, other than open mold fabrication
Types of Tooling	Can use a wide variety of tooling, including: Low-cost non-temperature controlled polyester molds; Temperature controlled laminated tooling; Mass cast tooling; Cast aluminum tooling; Electroformed nickel shell tooling; Machined steel tooling.	Typical open molding type tooling is adequate. Polyester tooling gel coat/polyester laminate molds are widely used. Epoxy tooling is an option. Flat panels may be molded from vacuum tight metal surfaces. Thin "hard-shell" male molds can replace the vacuum bag in some instances. Re-usable vacuum bags are possible.
Cost of Tooling	Can range from 5x to 50x the cost of open molding.	Can range from the same as open molds to 5x open molding.
Mold Handling	Requires mold-handling equipment to deal with the weight of molds. Perimeter clamping device or press is required to close mold set.	No special mold-handling equipment over and above open molding requirements.
Process Equipment	Mix/metering resin injection equipment required. Basic injection equipment begins at ~$10,000, and can be customized and automated to higher levels of functionality and cost..	Vacuum source required. Basic venturi vacuum pump ~$500. Higher capacity vacuum pump ~$1500+. Plant vacuum system is required for serious processing.
Cycle Times	Can range from 10 minutes to several hours. Faster than hand lay-up or spray-up open molding. Temperature controlled tooling can decrease cycle times substantially.	Generally slower than hand lay-up or spray-up open molding. Dependent on size of the part and how fast resin can be pulled into the mold. A long infusion time requires a long gel time resulting in a long cure cycle.
Solid Waste Generation	Trim scrap from part flange and incidental resin overflow from vents.	In addition to trim scrap, bagging materials and internal manifolding are disposable. Bag waste can be reduced by employing re-usable bags or hard-shell female molds. Re-usable bags are limited in size.
Styrene Emissions	Very low in a well-designed system. However, gel coat is applied by conventional spray methods.	Very low in a well-designed system. However, gel coat is applied by conventional spray methods.

Finished Part Cosmetics	Two-sided finish possible. Better surface finishes are possible with temperature-controlled tooling.	Difficult to achieve good cosmetics with thick laminates. A conventional hand lay-up skin coat may be required to produce a high quality surface finish.
Gel Coat Finish	Gel coat applied by conventional spray application. Two-sided gel coat finish possible.	Gel coat applied by conventional spray application. When using a vacuum bag, only single-sided gel coat finish possible. A two-sided gel coat finish is possible with hard-shell tooling.
Physical Properties	Higher properties than open molding can be designed into parts. Fiber loading of 35 to 50% by weight is typical. Up to 70% is possible.	Higher properties than open molding are expected. Fiber loading as high as 70% by weight is possible. Laminate void content can be very low, particularly with vacuum re-circulation methods.
Part Thickness Control	Designed into mold set. Assuming effective tool set clamping, thickness is determined by mold cavity dimensions.	Thickness influenced by reinforcement lay-up, fiber loading and amount of vacuum applied.
Process Capital Investment	Substantially higher than open molding, considering tooling and equipment cost. (Or substantially lower than compression molding). Sophisticated automated manufacturing systems can be built around the RTM process.	Slightly higher than open molding, with no increase in tooling cost. Minimal process equipment investment required.
Part Cost	Less than open molding, depending on cycle times, tool cost and system automation. Can approach near-SMC cost at the highest level of efficiency.	The equal to or slightly higher than open molding.
Part Complexity	Complex part geometry possible. Greater complexity increases tooling cost and reinforcement loading time. Reinforcement loading becomes process bottleneck. As part complexity increases, preforms become a required part of the process.	Complex part geometry possible. Greater complexity increases reinforcement loading time, increases the difficulty in mounting vacuum bag, and increases resin infusion time.
Part Size	Limited by tool structure, weight and clamping capability. Generally less than 100 sq. ft., although larger sizes are possible.	Very large parts can be molded, with parts up to 4000 sq.ft. demonstrated. Only minor tool structure constraints.
Process Learning Curve	Steep - Tool design and production handling equipment require experience. Few companies succeed at RTM initially, without obtaining expert advice and experience.	Shallow - Tooling is not an issue. The process is straightforward. Initial success rate is relatively high with entry-level experience.
Process Automation Capabilities	RTM systems can be highly automated, instrumented and monitored. Sophisticated production systems can be built around the basic process.	Not as readily automated as RTM. The reinforcement lay-up and bagging sequences are similar to open molding. The use of hard-shell male molds can eliminate the "hand configured" vacuum bag.

Section 5

Teaching the Controlled Spraying Technique

A review of application efficiency

The ACMA Open Molding Styrene Emissions Test Project has provided a large amount of information about emissions, including: the factors that effect emissions, the development of emissions during the process, and emissions mitigation techniques. In a broad analysis of the test results, one aspect stands out above the rest. While emissions can be reduced with lower styrene content resins, shorter gel times, and the use of suppressants, the single greatest effect in reducing emissions is controlled spraying. These application techniques apply to both traditional atomized spray as well as non-atomized flow coater application.

Controlled spraying can reduce resin spray emissions by as much as 20%, and gel coat emissions by up to 40%! The result is that the means are available to make substantial emissions reductions without changing materials, buying new equipment or engaging in a different molding process. You can improve material transfer efficiency, shop conditions and product quality while saving money. Facilities with effective controlled spraying programs report substantial material savings, in some cases as much as a 7-10% reduction.

The reason controlled spraying is a significant factor is that *overspray is a major contributor to styrene emissions*. Overspray increases the “wet footprint” of a mold. The emissions from a thin film of overspray are almost the same as from the surface of the mold - regardless of the laminate or gel coat thickness. Reducing the wet footprint area around the mold is the result of controlled spraying as compared to typical application methods.

Controlled Spraying is a method of increasing material transfer efficiency and reducing styrene emissions through minimization of atomization and overspray loss. This is accomplished by three means:

1) Operation of the spray gun at the lowest applicable fluid tip pressure
2) The use of proper spray gun handling techniques
3) The use of close capture mold configurations that minimize overspray surface area.

In this discussion the term *resin* is used generically to refer to unsaturated polyester laminating resin, or gel coat, which is a specialized form of resin used as an in-mold coating. Following are aspects of spray control, which when combined offer substantial emissions reductions over typical uncontrolled spraying:

Minimization of Atomization

In order to create a useful spray pattern, (and in many cases provide for external mixing of an initiator component with the resin stream), it is necessary to convert a pressurized stream of resin into a shaped pattern as the fluid exits the spray gun tip. This shaped pattern is known as the fan pattern. The act of atomizing the fluid is to break the fluid stream into small particle sizes, which convert the narrow high velocity fluid stream into a lower velocity, shaped fan pattern.

In order to achieve an acceptable fan pattern, and the proper mixing of initiator, a level of atomization is required. The level of required atomization will vary and is dictated by the characteristics of the resin rheology, resin temperature, spray gun type, required spray gun distance from the mold, and mold configuration. There is however, an ideal level of atomization for each combination of factors.

Any additional atomization beyond that required level to form an adequate fan pattern, (or provide for adequate initiator mixing), should be considered excessive. Over-atomization results in an increase in emissions from increased monomer evaporation and decreased transfer efficiency associated with enlarging the “wet footprint” of overspray.

The objective of *minimizing atomization* is to insure that atomization greater than required to produce an adequate fan pattern or to facilitate initiator mixing does not take place. This is accomplished by operating a spray gun at the lowest possible pressure that develops a proper fan pattern and initiator mixing for a given set of circumstances.

Minimization of Overspray Loss

Overspray is considered to be that resin which is deposited off of the mold surface during the resin spray application. This can be directly related to transfer efficiency, i.e. the amount of material dispensed by the spray gun, compared to the amount deposited and retained on the mold.

Overspray has the effect of increasing the resin surface area by creating an enlarged “wet footprint”, greater than the actual mold surface area. This increase in surface area contributes to an increase in emissions. Overspray can be minimized by three means:

1) Control of fan pattern
2) Control of spraying technique
3) Close capture at the mold perimeter.

Control of Fan Pattern

The size and shape of fan pattern should be compatible with the size and configuration of mold being sprayed. The objective is to use a fan pattern configuration that will allow the spray operator to cover the required area efficiently, while at the same time provide effective operator control of the material deposition on the mold surface.

Control of Spraying Technique

Efficient spraying technique consists of aiming the spray gun accurately and establishing a mold coverage pattern that minimizes overspray. This is accomplished by operator training, and verified through observation. An effective spray gun operators training program should incorporate the following elements:

1) Explanation of the requirement to spray efficiently.
2) Explanation of how overspray contributes to emissions.
3) The requirement to operate the spray gun at the lowest applicable pressure.
4) Proper spraying techniques:
    - Spray gun orientation perpendicular to the mold
    - Establishing a proper coverage pattern
    - Spraying the mold perimeter
    - Spraying corners
    - Spraying large and small molds

- Spraying male and female mold configurations
- Spraying flat surfaces
- Spraying curved surfaces

Close Capture of Overspray at the Mold Perimeter

The purpose of capturing overspray near the perimeter of the mold is to minimize overspray spread into an enlarged wet surface area. The primary method for close capture is to collect overspray as close as possible to the mold edge. This can be accomplished by; extending the perimeter flange of the mold; using a removable flange extension around the mold perimeter; or using disposable masking around the mold perimeter

Controlled spraying has the potential to keep more pounds of styrene emissions out of the air than any other technology, involving spray application. The more control you have over every phase of the production operation, the better. This will be realized by greater plant efficiency and better product quality. Controlled spraying does not have a downside; every aspect of the technique is beneficial to the entire production operation.

"Minimum Pressure for Maximum Performance"

"Where You Aim the Spray Gun Is Important"

Section 6

Efficient Non-Atomized Application

The advent of non-atomized application has provided the open molding industry with a useful and necessary tool to reduce emissions. Compared to traditional atomized spray gun technology, the capability of producing a coherent flow stream offers significant advantages. However, there are a number of issues that orbit the technology of delivering a high efficiency flow stream to a mold surface.

Low emissions spray guns were introduced to the composites industry in the 1980's in the form of relatively crude "sprinkler head" systems. The method employed by these original designs was to deliver a straight stream of resin from a multiple orifice spray tip. Where a typical atomized fluid tip has a single elliptical orifice, the sprinkler head systems employed from 3 to 20 round orifices configured to mechanically "aim" individual flow streams into the shape of a fan pattern. While these multiple orifice units proved sufficient for simple hand lay-up wet-out purposes, they fell short of providing an efficient fan pattern for spray-up (chopping) operations.

In the late 1990's the development of fluid impingement technology was an advancement over the previous multi-orifice systems. With fluid impingement, two flow streams are directed at one another a short distance from the fluid tip and the intersection of the impinging flow streams creates a fan pattern with coherent characteristics.

Fluid impingement delivery has been further refined from the initial designs. Additionally, the introduction of precision laser machining has resulted in the development of mono-orifice fluid tips that form the fluid stream into a fan pattern at the orifice. Under the umbrella of low pressure fluid delivery there are currently three core technologies available: Multiple-orifice (sprinkler head); fluid impingement; and mono-orifice delivery systems. Variations include internal and external initiator mixing and the addition of shaping air.

As these fluid tip technologies were refined it became apparent that the application of gel coat using a low pressure fluid stream was possible. In 2001 ACMA evaluated emissions from non-atomized gel coat application and developed emissions factors for this process.

Phases of Emissions Generation

There are distinct characteristics of the emissions profile for gel coat and resin application. This includes two phases during the gel coat emissions sequence – the transfer stage and the curing stage; and three phases during laminating resin application - the transfer stage, the roll-out stage, and the curing stage. During the transfer (spraying) phase a high peak concentration is produced in a relatively short time. In the curing phase lower concentrations are emitted for a longer period. In the case of applying resin to a laminate, the roll-out stage is introduced in the emissions curve. During the rolling process the disturbance of the wet surface and the cumulative surface area of the rotating roller are additive, resulting in higher emissions than the naturally declining emissions curve would produce in the undisturbed state (Fig 1).

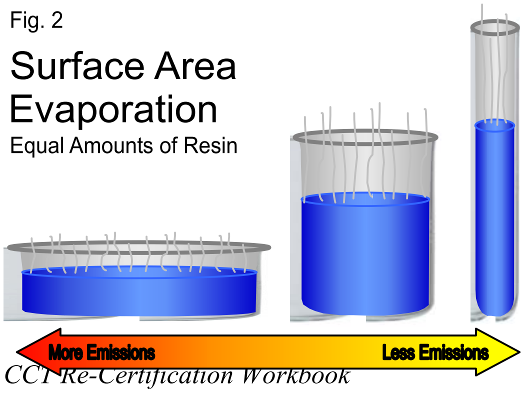
Although short in duration, transfer stage losses are a major contributor to overall emissions. Where curing stage emissions are inherent to the volatile content of the material and ambient conditions, transfer stage emissions are greatly influenced by the level of atomization of the spray pattern. The type of spray gun and the operational fluid pressure are major variables in the overall influence on emissions.

The Emissions Mechanism

There are two aspects of emissions that must be understood to grasp the mechanisms of the process – transfer efficiency and surface area. Transfer efficiency is relative to the amount of material that exits the spray gun and how much of that material is deposited on the mold surface. Transfer losses are distributed as evaporative loss and overspray loss.

During resin and gel coat application a certain amount of volatile component (i.e., styrene and/or methylmethacrylate - MMA) will be lost in the "tip to target" transport of the fluid. This evaporation is governed by a complex set of interactions involving the level of fluid stream atomization, material vapor pressure, temperature, rheology and other surface effects. The evaporative loss is greatly influenced by the percentage of monomer (styrene or MMA) available and is inherent to the formulation of the material.

Fig. 2


Surface Area Evaporation

Equal Amounts of Resin

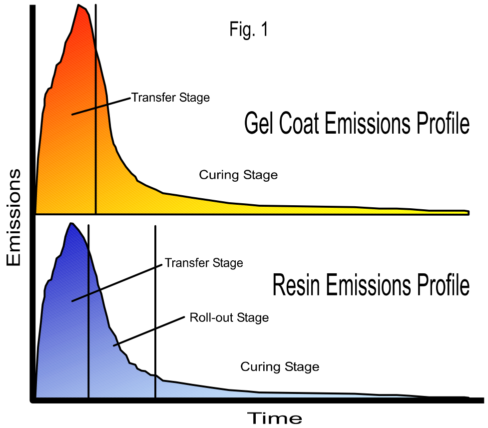


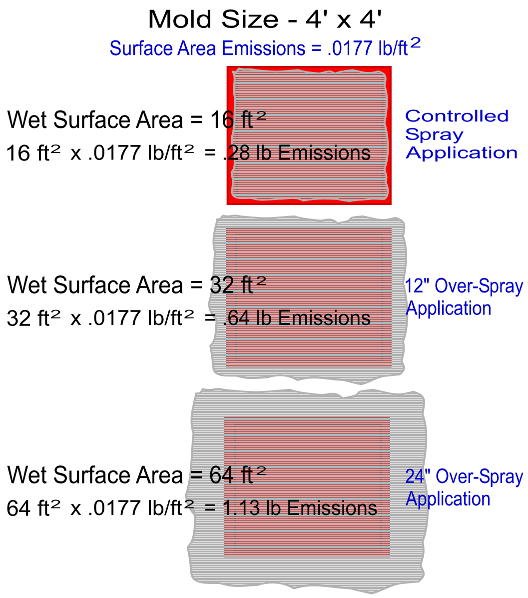
Fig. 1

Overspray is a byproduct of inefficient transfer and is controlled by spray gun pressure and operator spraying technique. Overspray is material that leaves the fluid tip and is deposited *off-mold*, on the floor, walls, or spray booth filters. Whereas, evaporative loss is inherent to the sum of the influencing factors on the material, overspray is determined by the level of spray gun atomization and handling of the spray gun.

Emissions from the open molding process are a function of the wet surface area of resin or gel coat. To illustrate this point (Fig. 2) the same quantity of resin is placed in three different containers; these containers present a variable surface area. Evaporative emissions are not a function of the volume of resin, but rather of the exposed surface area. To apply this principle to a wet laminate or gel coat film consider this; in the static (undisturbed) state, a thick laminate or gel thick coat film will produce the same emissions as a thin laminate or film assuming equal cure times. The emissions are not a function of the thickness, but rather surface area. Even in the case of a thick laminate that produces measurable exotherm, as the cure advances emissions will follow a curve similar to a thin laminate of the same surface area.

With the understanding that emissions are a function of surface area, the effect of overspray is to dramatically increase wet surface area. Figure 3 illustrates the impact of overspray on emissions. In this example, a particular combination of gel coat and conditions produces .0177 lb/ft^2 of emissions per wet surface area. This does not include transfer stage emissions. As shown, there is a direct relationship between the increase in wet surface area and emissions from relatively small volumes of overspray spread over a large area. This emphasizes the importance of controlled spraying techniques, and in the larger view illustrates the function of surface area effects on spray patterns during the transfer stage.

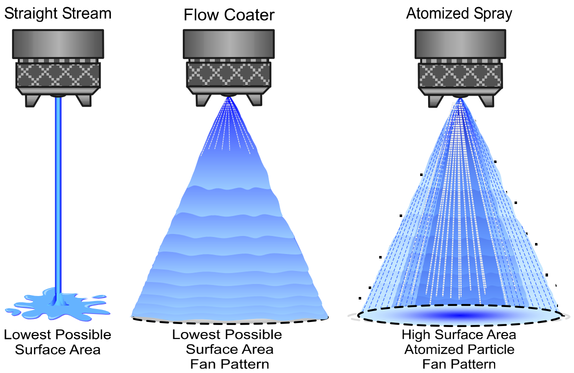
Fig. 3



Surface Area and Spray Patterns

The concept that surface area is a major determinant of emissions extends to spray gun fluid delivery. Figure 4 illustrates three modes of fluid flow. The straight stream represents the lowest possible surface area for delivery of a given flow rate of material. However, delivery in this form is not practical or useful for application to a mold. A low emissions spray gun presents the lowest achievable surface area spray pattern by using a coherent flow stream. And finally, the atomized fan pattern produces a large increase in surface area due to reduced particle size and the footprint created by associated overspray.

Fig. 4



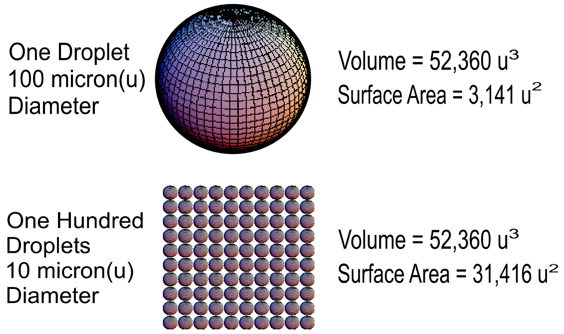
The purpose of a low emissions fluid tip is to modify a flow stream into a shape that is useful to distribute material across a mold. This is accomplished in several different ways. Impingement designs use two intersecting fluid streams to form a flat pattern. Mono-orifice designs direct the flow within the orifice to spread the stream into a fan shaped pattern. The older multiple orifice equipment produces a series of straight streams that are aimed into a fan shaped array.

A hypothetically perfect fluid nozzle would produce a coherent flow stream of the appropriate shape and width for efficient material coverage on a mold. This flow stream would represent the lowest surface area for a workable spray pattern. In reality, a perfectly coherent flow stream is not achievable in the shape of a fan pattern. In practical terms, an effective low emissions spray gun produces a coherent flow stream for a distance from the orifice; this flow stream transitions into ligaments and further into large droplets. In actual operation this form of fluid flow results in the lowest *achievable* surface area and produces emissions equal to or less than the UEF emissions factors. Because the coherent stream of a low emissions spray gun degenerates into ligaments and droplets, the particle size distribution within the spray pattern is of great interest when considering the lowest achievable surface area.

At some point on the fluid pressure curve, a coherent flow stream with ligaments and large droplets will be converted into a flow that is populated with small particles – this is the point of atomization. The affect of reducing large droplets into smaller particles is to significantly increase the effective surface area of the flow stream. Figure 5 illustrates the relationship between the size of fluid droplets and surface area. A single large droplet 100 microns in diameter has a volume of 52,360 microns^3 and a surface area of 3,141 microns^2. If that same droplet broken into one-hundred particles with a 10 micron diameter the same overall volume in maintained; however the surface area is now 31,416 microns^2, or a 10x increase in surface area. The result of this particle size reduction is a large increase in emissions during the short duration tip to target transport phase.

Fig.5

Particle Size Volume vs. Surface Area



The Relationship between Fluid Pressure and Emissions

Non-Newtonian fluids, such as resin or gel coat, are responsive to the abrupt pressure gradient as a fluid stream exits a spray tip orifice. As increasing fluid pressure imparts more "push" to the flow, the differential pressure causes a more energetic distribution of the flow across the spray pattern. This energy is manifested in a correlation between pressure and particle size distribution. Higher pressures produce a more energetic break-up of the fluid stream with smaller particles spread over a larger area.

With resin and gel coat application there is a direct correlation between tip pressure and emissions. Figure 6 shows a nearly linear relationship between pump pressure and emissions. In the case of atomized equipment it appears the linearity of the pressure /emissions curve is very predictable. With "non-atomized" fluid delivery the emissions curve may not be as linear or predictable. It appears that low emissions spray guns maintain a reasonability coherent flow stream through a certain pressure range and then within a narrow pressure band the flow stream transitions into what behaves more like an atomized flow. There are many variables that determine the particular pressure at which this transition takes place; however, there is a direct relationship between fluid tip pressure and emissions. Understanding this fact is an important aspect of equipment set-up and operation.

Why are Non-Atomized Resin and Gel Coat Applications Different?

The following table summarizes the differences between non-atomized resin and gel coat application.

Comparison of Non-Atomized Applications

	Resin Application	Gel Coat Application
Flow Rate	Less Critical	More Critical
Applied Thickness	Less Critical	More Critical
Initiator Mixing	Less Critical	More Critical
Air Entrapment	Minor Issue	Major Issue
Cosmetic Requirement	Minor Issue	Major Issue
Application Technique	Less Critical	More Critical
Material Sensitivity	Minor Issue	Major Issue
Temperature Sensitivity	Minor Issue	Major Issue

Compared to laminating resin application, gel coat presents two challenging aspects due to the nature of the product. Film thickness is a critical attribute of finished product performance. It is easier to produce a more uniform film thickness with atomized application than with a coherent flow stream. Likewise, porosity is a determining factor of finished gel coat quality. Porosity is more likely to be present with non-atomized applied gel coat, than with a highly atomized application. When considering resin, the applied thickness can be dealt with during the roll-out process and void inclusion (of the size that would affect gel coat) is not a major issue.

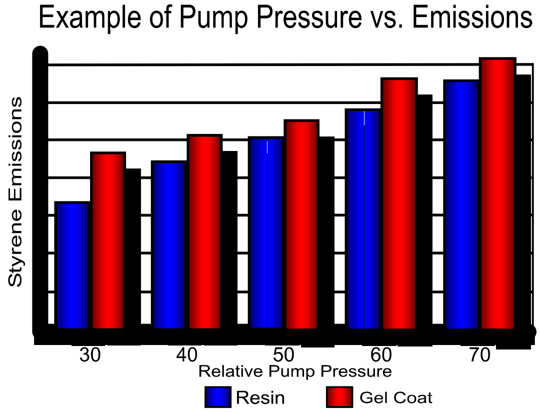
Gel coat can be successfully applied with low emissions equipment; however, the application parameters are more critical than with resin application. The equipment may require pressure settings in an operating range just below the threshold of atomization. While successful in some facilities, and for particular levels of quality, at this juncture it remains to be seen if "non-atomized" gel coat can satisfy the quality requirements across the broad spectrum of the open molding industry.

One issue is apparent in the consideration of non-atomized applied gel coat – The combination of the type and set-up of equipment and the specific gel coat formulation is more critical than with any other open molding material application. Whereas various combinations of laminating resin and non-atomized equipment are usually considered "plug and play", experience is showing that gel coat application requires careful fine tuning of the "equipment/materials system" to achieve acceptable quality.

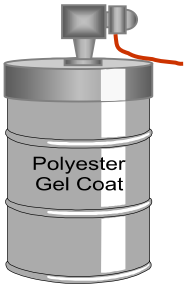
Proper Equipment Set-Up for Low Emissions Application

The set-up of low emissions equipment is a highly critical aspect of the process. The use of a "non-atomized" application device does not guarantee the result is a non-atomized flow stream that meets the UEF emissions criteria. With excess pressure it is possible to cross the line where the spray pattern converts from meeting non-atomized parameters to that of an atomized fan pattern. This conversion takes place when the ligaments and large droplets forming at the end of a coherent flow stream are converted into small high velocity particles signaling the onset of atomization.

Fig. 6

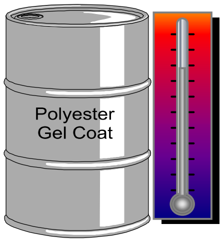


There are a series of simple steps in the recommended procedure to establish the appropriate fluid pressure for every combination of material and spray gun, including non-atomized and atomized units. This procedure produces the minimum achievable emissions from any combination of spray gun and material.



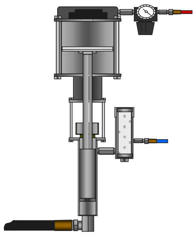
- ***Step One – Mix the Material***
Verify that the material has been properly mixed within 24-hours of use according to the manufacturers recommendations. Effective mixing requires the use of device that can impart a low shear to the material such as an air-motor powered drum-top paddle mixer or a somewhat less effective screw-type mixer. Attempts to mix material by bubbling air through the drum are highly detrimental to the quality of the material and completely ineffective in mixing. Likewise, attempts at mixing by rolling a drum on the

floor are completely ineffective. It is imperative to use an air-powered mixing device to properly mix the material into a homogeneous blend before use.



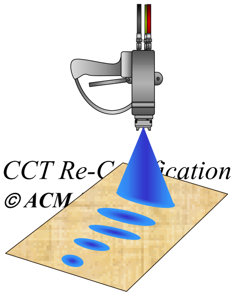
● ***Step Two – Adjust and Verify Material Temperature***

The temperature of the material in the drum is a critical element of the application process. The affect of temperature on viscosity plays a critical roll in the required pressure to pump the material to the spray tip. Most manufacturers recommend 70^{0}F as the *minimum* material temperature for effective application. (Refer to the manufacturer for a product specific recommendation). The use of in-line heaters for gel coat application has been found to enhance the sprayability of the product. However, note that in-line heaters are not a substitute for the proper temperature of material in the drum.



● ***Step Three – Spray System Checks***

Unrestricted fluid flow from the pick-up tube in the drum, through the pump and within the fluid lines, is essential to consistent pressure settings. Check and clean the pick-up tube screen and high pressure side in-line filters. Clean filters are required to provide the least restricted flow in the system. Check the wear condition of the spray tip – Spray tips erode through the abrasion of high energy flow and must be replaced on a routine basis to maintain optimal spray patterns.



● ***Step Four – Calibrate Spray Gun Pressure***

The lowest fluid tip pressure that results in a practical spray pattern will produce the lowest emissions for that combination of equipment and material. This pressure calibration procedure works with all spray guns, non-atomized and atomized, and with all materials including both resin and gel coat. While the quality of a spray pattern may be somewhat subjective and dependent on required quality, there are common characteristics of a workable spray pattern:

- The spray pattern is of sufficient width at the required distance from the mold.
- The spray pattern is uniformly ovoid or elliptical in shape.
- The fluid stream is evenly distributed across the width of the spray pattern.

The *Pressure Calibration Procedure* should be performed at the beginning of each day or shift, or if significant environmental changes during the day require pressure modifications. This procedure is simple, effective, and takes no more than a few minutes to accomplish.

► **<u>Calibration Step 1</u>** – If the spray gun uses external shaping air – Set the air-assist pressure in the middle of the normal operating range. Set the external mix initiator pressure at the required level.

► **<u>Calibration Step 2</u>** – Turn the fluid pump pressure down to the point where the pump will not stroke when the spray gun trigger is pulled.

► **<u>Calibration Step 3</u>** – Hold the spray gun perpendicular to, and about 12” to 18” from, a disposable covering on the floor. Pull the trigger and increase the pump pressure in increments until a workable spray pattern is formed. Once the pressure is near the optimum pattern formation, quickly pull and release the trigger to take a "snapshot" of the fan pattern shape. Adjust as necessary to refine the pattern with the goal of using the lowest pressure possible.

► **Calibration Step 4** – If applicable, fine tune the external shaping air and/or initiator mixing as required. Again, use the lowest pressure that produces a workable spray pattern.

► **Calibration Step 5** – Observe the non-atomized flow stream to be sure the transition to atomization has not taken place. If the coherent flow stream is degenerating into excess fine particles repeat the set-up process and lower the fluid pressure.

► **Calibration Step 6** – Record the pressure settings in a daily log.

This calibration procedure will produce a repeatable equipment set-up that can be optimized for a wide range of equipment, materials, conditions, and quality requirements. In Calibration Step 5, if a coherent flow stream cannot be established into a workable fan pattern, it may be necessary to make adjustments to the combination of material and equipment type. It is recommended that molders work closely with material formulators and equipment suppliers to develop the appropriate combination of material, spray gun set-up parameters and application conditions.

The use of non-atomized application is a significant benefit to composites open molding production. However, misuse of the process by over-pressuring the spray gun may lead to higher than expected emissions. By understanding the emissions mechanism and the techniques for calibrating equipment, the objective of reducing process emissions an achievable goal. The resulting increase in transfer efficiency not only leads to emissions reduction, but provides measurable cost savings and a cleaner production environment. ⌘

Non-Atomized Application Glossary

Air-assist (assist air or shaping air) – Auxiliary air flow introduced into the fluid stream at the spray tip for the purpose of enhancing the shape of a spray pattern.

Atomization – To reduce to minute particles or to a fine spray.

Coherent flow stream – A sheet of liquid that is produced by a specialized fluid nozzle that stays substantially intact, i.e., without breaking into smaller droplets or fine particles.

Controlled spraying – A method by which spray gun pressure and spraying technique is controlled to enhance transfer efficiency. Controlled spraying application has specific emissions factors associated with the technique that are used for certain regulatory purposes.

Curing stage – The quiescent or static phase of laminate or gel coat curing when the surface is undisturbed.

Droplet – the quantity of fluid that falls in one spherical mass.

Emissions profile – A graphic plot of emissions vs. time.

External mix – Plural component equipment that combines initiator with resin or gel coat outside the gun head.

Fan pattern (spray pattern) – A fluid stream formed into an ovoid or elliptical shape and used to dispense a coating or resin.

Flow coater – A term sometimes associated with low emissions spray guns. This equipment is designed to form a fan pattern without atomization of the flow stream. Low emissions spray gun types are designated as fluid impingement, mono-orifice, or multi-orifice. For regulatory purposes OSHA considers a flow coater a continuous sheet device used on a conveyor system and has associated regulations that govern the use of this equipment. These "flow coaters" bear few similarities to a coherent stream capable spray gun.

Fluid impingement – A method of forming a fan pattern that uses two intersecting fluid streams to create a coherent sheet of material.

Fluid pressure – The pressure created on the hydraulic side of an air-over-fluid pump; refers to the pressure from the fluid section of the pump, through the material lines and to the spray gun. At the spray orifice fluid pressure is referred to as tip pressure.

Internal mix – Plural component equipment that combines initiator with resin or gel coat inside the gun head using a static mixing device.

Ligaments – When referring to a coherent flow stream, the initial degeneration of the stream comes as high aspect ratio droplets break off the sheet. These long and very large droplets become progressively smaller as they move away from the coherent fluid sheet.

Mono-orifice low emissions spray gun – A coherent stream capable device that uses a single orifice configured to spread a low pressure fluid stream into a fan pattern.

Multiple-orifice low emissions spray gun - A coherent stream capable device that uses multiple orifices (3-20) to form an array of a flow streams into a fan pattern.

Non-atomized application – A method of dispensing resin or gel coat that employs a coherent flow stream.

Non-atomized equipment – Spray equipment that is capable of producing a useful fan pattern that does not rely on atomization for material distribution across the spray pattern.

Overspray – Material dispensed by a spray gun that is not transported to the mold or target surface. The quantity of overspray determines transfer efficiency.

Particle - a relatively small or the smallest discrete portion or amount of something. In the context of spray patterns a coherent flow stream degrades into ligaments, droplets and finally atomized particles.

Pump pressure – In a typical air-over-fluid pump, "pump pressure" refers to the input air driving the air motor. The air motor input pressure is multiplied within the fluid (hydraulic) section of the pump creating a higher fluid pressure flow to the spray gun.

Roll-out stage – During the laminating process the roll-out stage occurs when the laminate is compacted by hand using an FRP roller or other compaction tools.

Shaping air – (air-assist or assist air) – Auxiliary air flow introduced into the fluid stream at the spray tip for the purpose of enhancing the shape of a spray pattern.

Spray Pattern (fan pattern) – A fluid stream formed into an ovoid or elliptical shape and used to dispense a coating or resin.

Surface area – In the context of spray application: the exposed area of mold to which material is applied; the footprint of an overspray plume; or the effective size of a spray pattern based on particle size distribution.

Transfer efficiency – The amount of material dispensed through a spray gun compared to the amount that is deposited on the target surface.

Transfer stage – The time during a molding operation where material is flowing from the spray gun to the target surface.

UEF Emissions Factors – Unified Emissions Factors; A set of emissions factors developed by ACMA and NMMA and currently in use by the composites industry and Federal and State regulatory agencies.

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Section 7

MACT Misconceptions

Understanding the EPA Regulation

The EPA's Maximum Available Control Technology (MACT) Standard is upon the composites molding industry. However, after more than a decade of research, negotiation, task group meetings, and education on the EPA Standard, there are still a number of misunderstandings that circulate through the industry. Depending on who is doing the explaining, MACT could be responsible for everything from shutting down open molding operations, to causing the widespread adoption of closed molding, or limiting production in some fashion. In general terms none of this is true. Misconceptions about MACT abound, as witnessed in casual industry conversations and organized product marketing campaigns. This discussion focuses on the requirements for reinforced plastics composites manufacturing facilities. The MACT Standard for boat building has similar elements and some differences that are not specifically addressed in this dialog.

During the twelve years of MACT development, the industry successfully negotiated a Standard with the US Environmental Protection Agency. The industry applied pressure to the Agency to consider the realities of an emissions standard that would be reasonable and based on sound science, statistics, and economic data. To that end, the industry prevailed. Due to these efforts, the MACT Standard is workable for a vast majority of composites molders. Workable is defined as involving some changes in materials and application methods, but not creating sweeping disruptive changes or causing an undue economic burden.

Misconception #1 – MACT is going to harm the open molding industry.

Not true. The fact is the MACT Standard actually supports the continued existence of open molding. For a vast majority of open molding plants, MACT compliance will consist of using lower HAP resins and gel coats, and non-atomized application of resins. Compliance, which is within practical reach of most operations, actually results in an extended viability of the open molding process.

Only newly constructed facilities planning to discharge over 100 tons of emissions per year will be subject to expensive engineering controls. This will apply to a very limited number of facilities in the future. Most companies subject to MACT will have to make some changes; however, the economic reality is well within the grasp of the average facility.

A valid argument can be advanced that in the long run MACT will actually produce an economic benefit. In manufacturing, consider that any material that is purchased, and is not present in the finished product, is waste. This includes emissions that have gone up the stack and overspray associated with atomized application. Significant savings in materials consumption are being documented by operations in compliance with MACT and using pollution prevention methods. Another benefit includes reduced employee exposure to styrene. While somewhat more intangible, a cleaner workplace and better employee retention can result from the reduction of waste and emissions.

Compliance with MACT will not have a detrimental affect on open molding operations, and will benefit companies savvy enough to take advantage of higher levels of efficiency.

Misconception #2 – MACT will place an undue economic burden on the industry

In most cases, the changes required under MACT will not result in a serious economic burden. In fact, MACT compliance could actually produce an overall savings assuming engineering controls are not required. While there may be a cost differential between low-HAP and traditional higher HAP resins and gel coats, this difference can be off-set by material savings using pollution prevention techniques. Likewise, the cost of updating older application equipment to new non-atomized spray guns will not be an economic burden on operations subject to MACT. Historically, the plural component spray equipment used in open molding has a lifespan of about seven to ten years. For many companies their old airless-air assist spray units are coming to the end of there useful life regardless of the status of MACT. It has been determined that the material savings associated with the changeover from older atomized equipment to current non-atomized equipment can realize a return-on-investment of less than six months in the average open molding operation. The resulting cost of MACT compliance will be significantly offset by improvements in efficiency.

Constructing a large new molding facility will take some consideration if planned emissions will exceed 100 tons per year. This is limited to a previously non-existent plant that will process something on the order of 1.2 million pounds of resin and 250,000 pounds of gel coat annually. In this case capture and control is mandated. Studies have shown that at this production level the installation of engineering controls becomes more feasible and is many times necessary simply to control nuisance odors. Two options exist for developing a brand new high-volume open molding operation – install capture and control devices, or build multiple facilities that emit less than 100 tons of emissions per year. It has been determined that the potential for new facilities of this size will be very limited over the next number of years.

Misconception #3 – You must use specific materials to comply with MACT

The short answer is yes and no. The EPA does not specify particular materials or application techniques within the MACT Standard. What is included in the Standard are HAP-thresholds permitted with certain types of application methods. For example, when using non-atomized resin application a non-corrosion resin HAP level must not exceed 38%. However, this seemingly simple statement requires a broader background to be placed in the proper context.

Can you continue to use atomized application and comply with MACT? Yes, if the atomized application is used with an appropriately low HAP resin (30% - non-corrosion resistant resin). Can high-styrene resins or gel coats be used? Yes, if these high-HAP materials can be off-set by averaging with low-HAP applications.

The question concerning MACT compliant materials must be answered in the context of *combinations* of HAP-levels and application methods; or the ability to average high emitting processes with lower emitting processes. You may be able to use higher-HAP materials with non-atomized application and with a vapor suppressant. Or you may be able to apply resin using atomized spray with a very low-HAP resin.

MACT compliance is contingent on combinations of materials, additives, and application methods, rather than any single material or type of equipment. While no specific materials are specified, suppliers have available materials that fit into the combinations that produce the appropriate emissions results.

Misconception #4 – Companies will have adopt closed molding as a MACT compliance tool.

Under MACT, closed molding is not a "control" for open molding. While closed molding offers an emissions reduction advantage over open molding, it is a different process with unique emissions factors. In other words, one is not compelled by MACT to exchange open molding for closed molding. Within the MACT Standard, control options for open molding consist of using combinations of reduced HAP materials, vapor suppressants and lower emitting application equipment. Closed molding is not an extension of required open molding controls.

To refine this frame of reference, consider that there are MACT controls for a number of molding processes including open molding, closed molding, pultrusion, SMC compounding, and others. The MACT requirements are specific to, and compartmentalized within, a process. For example, there are compliance requirements for pultrusion, but this does not include exchanging pultrusion for compression molding. With open molding, the compliance requirements are not exchanged for closed molding. Closed molding will reduce emissions, and is subject to MACT closed molding requirements *as another process*, but is neither a substitute nor a control for open molding.

Emissions from closed molding (including RTM) and pultrusion molding cannot be used to "average out" emissions from open molding processes. (However, emissions from vacuum bag molding, which under MACT is considered to be an open molding process because the resin is applied to an open mold, can be used in averaging with other open molding operations.)

With that said, if a facility is bumping up against it's permitted emission cap, changing some production over to closed molding might be a way to continue to grow the business without exceeding an emissions permit limit.

Misconception #5 – MACT is an emissions limit.

MACT is not a facility emissions limit. The MACT Standard specifies technology that limits emissions on a per unit basis, but it does not specify how many units you can use. MACT does not limit the overall quantity of emissions from a facility. The emissions limit for a molding facility is a function of a negotiated State operating permit. A company can apply for an operating permit for any level of emissions. Assuming a successful negotiation and acceptance by the State regulatory agency, emissions permits can be any size required.

MACT does not place a cap on the gross quantity of emissions, but rather requires certain technology be in place for compliance. An analogy is EPA fuel mileage requirements for automobiles. The agency requires an average specified fuel mileage from an automakers fleet, but there is no limit on how many miles you drive your car. Likewise, with MACT certain criteria must be met for compliance. But the amount of resin or gel coat processed and the amount of emissions going out the stack are limited only be your State permit and not by MACT.

Misconception #6 – MACT is an emissions factor.

The Standard includes emissions factors for compliance, but MACT is not an emissions factor per se. There is a difference between MACT compliance factors and the factors used to report emissions other purposes. Operating permit compliance and Federal or State emissions reporting may use similar but different emissions factors. These emissions factors are based on the Unified Emissions Factors (UEF) but contain different elements. For example, controlled spraying is not a compliance option under MACT. However, the emissions factors for controlled spraying may be used for either permit compliance or emissions reporting.

Misconception #7 – You cannot use a high HAP resin or gel coat within MACT.

MACT dictates emissions per unit based on specific combinations of HAP-levels and application methods. Included in the MACT Standard is an averaging function. It is possible to use either high HAP materials or a high emitting process *if* those emissions can be offset by averaging with lower emitting processes. For example; a custom molder uses a large quantity of low-HAP materials in a non-atomized application. If they take a job that requires a particular high-HAP resin, this material can be averaged with the larger portion of low-HAP materials in use. In the event a high-HAP resin is used, it can become a MACT compliance problem if there are no lower emitting processes to use for averaging. However, under the MACT scheme this is a somewhat unlikely potential.

Misconception #8 – MACT will limit production.

The MACT Standard in no way limits production. In most cases, based on a company's State operating permit, production is limited by the permitted emissions cap. If emissions can be reduced, more product units can be produced. Assuming the plant is using traditional materials and application equipment, moving into compliance with MACT will reduce overall emissions. This will actually allow more units to be produced while staying within the State permit requirements.

--------- MACT FACTS -----------

What is MACT?

Maximum Available Control Technology Standard promulgated by the U.S. Environmental Protection Agency under the National Emissions Standards for Hazardous Air Pollutants (NESHAP). It is a result of the Clean Air Act Amendment of 1990.

What is a HAP?

Hazardous Air Pollutant - an EPA list of 189 chemicals. This includes styrene and methylmethacrylate (MMA) commonly used in polyester or vinyl ester resins and gel coats.

Who is subject to the MACT Standard?

Reinforced plastics composites manufacturing facilities that are major sources. A major source has the potential to emit, assuming continuous operations and without add-on control, 10 tons/year of any one HAP or 25 tons/year of any combination of HAP's.[1]

What processes are included under the composites MACT?

- Open molding
- Closed molding
- Centrifugal casting
- Continuous lamination/casting
- SMC/BMC manufacturing
- Pultrusion
- Mixing
- Storage
- Equipment cleaning

When is the MACT compliance deadline?

- Composites MACT - Existing sources – April 21, 2006
- Composites MACT – New sources – on start-up

What are the open molding compliance options for MACT?

The Standard specifies a HAP emissions threshold. This threshold can be met by using any one, or any combination of the following that produces a compliant emissions value:

- Low HAP resins or gel coats
- Vapor suppressant additives
- Non-atomized application techniques
- Covering containers, mixers, and resin baths

An additional compliance option is the use of capture and control engineering devices, such as a thermal oxidizer to treat stack emissions.

What about building a new plant?

A new facility of less than 100 tons/year emissions, where construction started after August 2, 2001, is subject to MACT compliance options. A new source greater than 100 tons/year of emissions is subject to the installation of capture and control devices.

What is averaging under MACT?

If a facility uses a variety of combinations of HAP levels and/or application methods for its open molding operations, the emissions values can be averaged to result in compliance with HAP threshold limits.

Will MACT actually reduce emissions?

Compliance with MACT will reduce emissions per unit of material used, compared to the baseline emissions of higher HAP materials and traditional atomized application methods. MACT does not limit overall stack emissions which are subject to State operating permit caps.

How do the new lower HAP materials and non-atomized equipment perform?

Many open molding companies across the composites industry have been successfully using both low-HAP resins or gel coats and non-atomized application equipment for some time. Reports indicate there is a learning curve and additional operator training required in making the transition to new materials and techniques. Reported benefits are significant savings due to waste reduction, reduced employee exposures to

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styrene and MMA, and better housekeeping in molding areas.

When do we *really* need to begin MACT compliance?

Now is not too early to begin coming into compliance. For existing sources, the compliance deadline is April, 2006.[2] The potential changes in materials, equipment, and operator training could have an impact on product design, production quality, and application methods. It is recommended to begin this transformation with enough latitude to experiment, train, and settle on the combinations that are most effective in your operation. Since the materials and equipment are currently available, a well planned introduction will certainly be more effective than a last minute rush to beat the compliance deadline.

Can the industry survive and prosper under the MACT Standard?

Yes. We will do just fine adapting to MACT assuming a willingness to give up the old ways and use the more efficient new technologies. Currently, of much more concern to the industry than MACT, are developing risk-based rules from EPA, reductions in the styrene worker exposure limits, and the potential for a reclassification of the health effects of styrene. ACMA is closely monitoring these developments and interacting with the agencies involved.

How do I handle MACT recordkeeping?

ACMA has software available to record, calculate and compile monthly reports for MACT compliance. This includes tracking a 13-month rolling average of materials consumption for annual reporting. Information on this reporting tool can be found in the members section of the ACMA website: www.acmanet.org

Where can I get more detailed information about MACT?

The ACMA website member's area contains detailed information about the MACT Standard, along with calculators and compliance tools: www.acmanet.org

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Endnotes:

[i1] This discussion refers to the NESHAP (MACT standard) for reinforced plastic composites manufacturing. The composites NESHAP applies to the use of styrene-containing thermoset resin to make products, including non-reinforced products, but not including boats. For boat builders, there is a separate MACT standard, with different requirements and compliance deadlines.

[1] Almost all open molders and cast polymer manufacturers are major sources, but many smaller operations can avoid official major source designation and MACT requirements by obtaining state permits as synthetic minor sources. A discussion related to this topic is available at http://www.acmanet.org/members/ga/mact_and_permits.pdf.

[2] If you use averaging for some or all of your open molding operations, you will not have to demonstrate compliance for those processes until April, 2007. But be careful – if it turns out at that date that you were not in compliance for the preceding 12 months on average, you will likely be cited and fined by your state.

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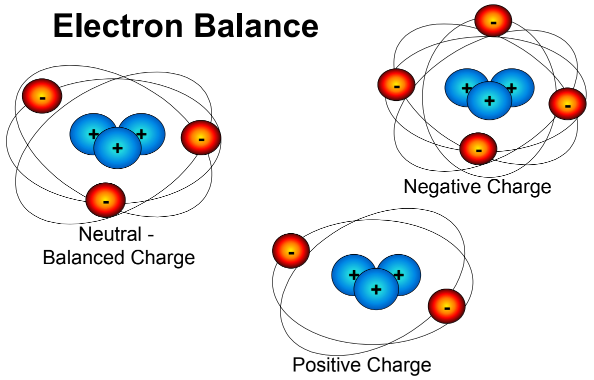
Section 8

Electrostatic Discharge (ESD) Hazards In Composites Operations

Things were humming along as usual in the mold shop of a large boat manufacturing plant. The relatively new plant is clean, well organized and busy producing a well-known line of sport fishing and motor yachts. As a flow chopper operator leaned in toward a mold for better reach, he felt a small static shock from the mold – the outside air was cool and dry - typical winter humidity in the 30% range. The kind of day when fiberglass dust gets sucked up your pants leg from the friction of walking. The chopper operator leaned in again stretching for the far side of the mold, and without warning ZAP – static spark – the mold was on fire!

There is nothing scarier than fire in a composites plant. Things happen faster than you can imagine, the smoke is black and dense - chaos ensues. In this case the chaos was controlled and the response was good. Fortunately, the mold was located near an overhead door, which was immediately opened, and the mold was pushed out of the building and extinguished. No injuries, no building damage, only minor mold damage occurred. However, the outcome could have been much more serious had the circumstances been slightly different. Once the adrenaline rush began to subside everyone in the plant started asking the question, "How did this happen?" We were doing the same thing we do every day and a wet laminate spontaneously combusts in our face. "Houston, we have a problem."

The problem in this example is electro-static discharge or EDS. In this case several factors came together to create a new set of conditions, which have not been widely experienced through the industry. This boat plant was using a flow chopper and conductive molds. That is FRP molds built using conductive tooling gel coat. This combination coupled with low atmospheric humidity produces a situation, which warrants serious attention.



What is static electricity?

All matter is composed of atoms. Atoms consist of electrons orbiting a nucleus. In the state of equilibrium, the positive charge of the nucleus equals the negative charge of the electrons. Electrons, however, are not very loyal to their nucleus. They come and go as the electrostatic equilibrium of surrounding atoms change. If electrons leave an atom, the atom becomes positively charged. If an atom gains extra electrons, it develops a negative charge. Given the opportunity to reach a neutral state, electrons from negatively charged atoms will migrate to positively charged atoms until an electrostatic balance is achieved. The development of a "static charge" occurs when an insulator is introduced into the atomic system. An insulator prevents the flow of electrons up to the point where a great enough charge (push) develops to bridge the insulated gap. In this case, great quantities of electrons are transferred almost instantaneously. On a small scale this is a static spark, on a large scale we know it as lightning.

The ability of a material to either shed electrons or attract electrons is known as conductivity. Good conductors, such as copper, have a rigid molecular structure that does not allow electrons to be easily released. Poor conductors such as thermoplastics and FRP composites will surrender their electrons easily when provoked by contact, friction or pressure. Not only do many nonconductive materials easily lose electrons, but also they act as an insulator causing a build up of excess electrons on their surface. When the electron imbalance becomes large enough, a discharge will take place to the nearest conductive material. Electrostatic discharge (ESD) occurs to bring atomic equilibrium back into place. The discharge can range from a few thousand volts developed while petting your cat, to millions of volts witnessed in an earth to cloud lightening discharge.

The level of static discharge we may come into contact with on a normal basis can range from 1,500 volts up to as high as 35,000 volts. Remember that when dealing with humans and electricity it is *amperage* that determines the potential hazard. The term *volt* refers to the quantity of electrons that are available for a discharge. Amperage measures the "push" behind the flow of electrons. In terms of contact with electrical discharge, high voltage at low amps is many times just an annoying static zap. On the other hand, low voltage with amperage can be deadly. For example, typical household current of 120 volts at 15 amps can cause a severe shock hazard, whereas 220 volts at the same amperage can easily cause death by electrocution. With static electricity we are talking about high voltage and low amperage. For example, walking across a carpet may generate 1,500 to 35,000 volts. Opening a plastic bag can produce 2,000 to 12,000 volts. When you feel a static discharge you are experiencing a minimum of 3,000 volts – anything less is below the threshold of human sensation.

Fiberglass composites have high dielectric strength. This refers to the level of conductivity of a material. Copper or steel have low dielectric strength because they are good conductors. Glass fiber laminates are poor conductors and resist electrical transmission by being good insulators. However, by virtue of being a poor conductor, a glass fiber laminate may accumulate very high static surface charge. Electrons build up on the surface of a mold, and because it is a good insulator, they cannot easily bleed off in a controlled incremental fashion. The surface charge on an FRP mold surface can reach 30,000 to 60,000 volts under certain conditions. When an open mold develops "dust stars" on the surface, a charge of at least 6,000 volts is present.

How is Static Electricity Generated?

There are two primary mechanisms to generate an electrostatic charge – friction or contact and separation. We are all familiar with friction caused static. When you walk across a carpet friction charges your body, which promptly discharges when you touch the doorknob. When the humidity is low and you walk across the FRP shop you will generate static within your pants legs, which will promptly draw fiberglass dust up your legs. If you insist on wearing pants made of synthetic fiber, a much higher charge is developed and more dust is drawn higher up your legs, resulting in discomfort that can border on immense. In the winter, cotton clothing is the only way to go in the fiberglass shop.

There are other ways of developing friction, which may become hazardous. For example, fluid flowing through a spray gun hose causes a static charge to develop. Even a liquid, such as acetone, being poured out of a drum spout will develop a static charge. But the granddaddy of all static generators in the FRP shop is the chopper gun. Non-conductive gun roving is pulled through roving guides at high speed. The friction that results turns a chopper system into a virtual static generator.

Static generated by contact and separation is experienced when we remove a part from a mold. We have all experienced the typical scenario – you've driven the wedges in around the flange and the part is loose in the mold. You then grab the flange and lift the part from the tool. The first thing you feel is all the hair on your arms stand-up, then all the resin particles leap onto your cloths, and as you lift the part further… ZAP. A discharge takes place – 30,000 + volts equalizes the surface charge. That is contact and separation.

Understanding Static in the Molding Shop

Spray guns develop an electrostatic charge because of the friction of fluid moving through the spray lines. Typically high-pressure fluid lines have an inner lining of high-density polyethylene, which is a non-conductive thermoplastic. As resin or gel coat flows through the line friction occurs, which produces a charged fluid stream. Also, when the fluid exits the spray tip, a contact and separation charge may develop.

Chopper guns add to problem by virtue of pulling gun roving through a series of roving guides on the way to the gun. Using metal roving guides (or homemade cardboard tape roll cores) creates a very high charge as the roving is pulled through the guides at high speed. This action charges the spray rig boom as well as the gun roving. If grounded properly, the boom will bleed off the charge, however the non-conductive glass roving will retain a considerable charge. Additionally, as the already charged roving runs through the chopper mechanism a substantial charge may be imparted between the cot and the blades. The glass will retain a very high charge out of the chopper chute if the unit is not properly grounded.

Surface charge on molds is another aspect of this problem. Since typical FRP molds are non-conductive, they can not be effectively grounded. Even if a mold has a metal substructure and the metal is grounded, the mold will still retain a surface charge. The charge may bleed off slightly in the areas of metal framework, but for the most part the laminate effectively insulates the grounded frame from the mold surface. Molds become charged by several means – removing parts, friction from rubbing the surface during waxing, and accumulating electrons from charged chop on the surface.

The non-conductive nature of FRP molds works for and against us. Electrostatic charge cannot be effectively bled off the surface. However, when an electrostatic discharge (EDS) occurs, it only discharges a local portion of the surface and not the entire surface. This phenomenon reduces the severity of EDS by reducing the quantity of electrons transferred during the discharge.

Dealing with Spray Guns

Much of the electrostatic discharge issue involves resin or gel coat application equipment. Because of this all fluid handling equipment MUST be properly grounded. Electrical continuity must be established from the body of the spray gun, through the fluid hoses to the pump and to a known ground. High-pressure fluid lines have a ground wire incorporated in the hose jacket. This ground wire must be in contact with the fittings at each end of the hose. (Check with your equipment supplier for the specific procedure to establish a ground with your fluid lines). It is highly recommended that a separate ground wire be run from the spray gun back to the resin pump. This wire should connect the metal body of the gun and be bundled with the hoses leading back to the pump unit. The pump in turn should be connected to a confirmed earth grounding point. It is easy to confirm a complete ground circuit using a low cost continuity meter. A $29 Radio Shack multimeter will do just fine to confirm that a ground is established.

Please take note that it is an OSHA requirement to have all spray equipment properly grounded. You *will* be fined if improperly grounded fluid handling equipment is noted during an inspection. Additionally, your insurance company requires proper grounding. Poor handling of this important aspect of safety could affect your premiums.

Chopper Gun Precautions

Chopper systems add another aspect to the static problem. As previously noted the chopper system is a highly effective static generator, but there are several methods to reduce potentially hazardous discharges.

1) Always use ceramic roving guides from the roving creel out to the end of the overhead boom. Never use plastic funnels, tape roll cores, or plain metal guides. The ceramic guides substantially reduce the charge of the roving flowing through the guides. Do not allow shop personnel to place non-standard roving guides in the system.
2) Ground the overhead boom and confirm continuity from the end of the boom to a known earth ground.
3) Be absolutely certain the chopper unit is properly grounded to the spray gun. Again confirm the continuity from the chopper chute to a known ground point.

Flow Choppers – A New Static Problem

With the advent and increasing use of flow choppers there is growing notice of a greater static problem with these units as compared to a traditional spray gun. The chop (chopped glass exiting the chopper chute) seems to be more highly charged than is normally noted with an atomized chopper gun. Additionally, there is anecdotal evidence that gun roving from different manufacturers may be either positively or negatively charged! In certain cases the chop “fluffs” on the mold surface, being repelled by the charge in the mold. This phenomenon has caused some operators to change suppliers or even mix two strands of roving from different suppliers.

Here is the current thinking on the flow chopper EDS problem: With a traditional atomized spray gun the electrostatic charge of the material exiting the spray tip is carried by the atomized particles. The fan pattern presents considerable surface area and allows much of the accumulated charge to bleed off into atmospheric moisture. However, with a flow coater the coherent streams of resin present minimal surface area. This minimizes the opportunity for the charge to be neutralized by natural means. Additionally, the multiple streams of a flow coater present 20 – 40 contact and separation points at the fluid tip compared to only one on an atomized spray gun. Where an atomized spray pattern seems to have the ability to carry off a charge, multiple flow streams seem to generate greater electron imbalance.

Because of the higher levels of charge apparent in flow coaters, for the first time the sizing on the continuous strand roving has become an electrostatic issue. *Sizing* is the chemical treatment on the surface of glass fiber filaments. The sizing enables the handling of the filaments and more importantly acts as an interface to bond the resin to the glass fiber. Sizing formulations are proprietary from each of the glass manufacturers, and are designed with the handling, wet-out and laminate properties of the glass in mind. It appears that different sizing formulations can produce either a positive or negative charge as the chopped glass exits the chopper chute.

In observing the interaction of the glass-charging phenomenon, it appears that if the chop is positively charged and the mold is negatively charged, the chop lays down well. On the other hand, if the chop is negatively charged and the mold is negatively charged, the chop seems to be repelled from the mold surface resulting in the observed "fluffing" of the chop.

As a result these problems it is much more critical to *ground* all components of a flow chopper. Some flow chopper manufacturers have installed a separate grounding lug on the chopper chute to bleed off as much charge as possible at the last contact with the ejected chop.

Conductive Surface Molds – A Warning

Conductive tooling gel coat was originally developed to promote electrostatic gel coat application. In electrostatic spraying the mold is negatively charged and the spray pattern is positively charged. The sprayed material is attracted to the mold surface, which promotes even coverage. While electrostatic gel coating has not been successful for several reasons, the use of conductive gel coat has continued. Many fabricators have found that the conductive gel coat produces a durable, high gloss tooling finish – regardless of its electrical properties.

Conductive surface molds present a new level of challenge and awareness in terms of dealing with ESD. As previously mentioned, a typical non-conductive mold will only bleed off the surface charge from a local area during a discharge. However a conductive surface mold, by virtue of being conductive will discharge the entire mold surface in one contact. Because of this conductive surface molds have a much higher potential for a high voltage discharge than their non-conductive counterparts.

In the electrical world a *capacitor* is two conductive surfaces separated by an insulator. When the charge of one of the conductive surfaces becomes great enough to bridge the insulating gap, a discharge takes place to the other conductive surface. A mold made from conductive tooling gel coat is a big capacitor. The conductive surface accumulates a charge and is insulated by the non-conductive laminate. When another conductive object, such as the human body, comes close enough the capacitor discharges the entire mold surface.

Molds with conductive tooling gel coat surfaces *must be grounded* at all times to prevent hazardous ESD. There are two recommended methods of grounding conductive surface molds. One is to drill a countersunk hole on the mold flange and place a flathead brass bolt in contact with the tooling gel coat. The bolt is then grounded. The second method is to place a fine copper screen in the wet gel coat around the mold flange during mold construction, then mount a brass ground bolt through the flange. The grounding lugs must then be connected to a known grounding point.

Preventing Hazardous ESD in Composites Operations

There are several aspects of static discharge mitigation to consider – equipment, molds, environmental conditions, and devices to reduce static electricity.

Equipment – Ground all fluid handling equipment and pay particular attention to grounding flow coaters and flow choppers.

Molds – Ground all conductive molds. This includes molds with conductive tooling gel coat surfaces and metal molds. Ground all metal fittings in non-conductive molds, such as blow-out ports or metal trim edges.

Ground the metal structure on the backside of a non-conductive mold in *not* an effective method of bleeding static charge off the mold surface, it can however prevent shocks from touching the metal structure.

Environmental Conditions – Low humidity is a prime factor in ESD. When atmospheric moisture drops below 50% relative humidity (RH) and static problem may develop. In the winter it is important humidify the plant production areas. On the high end humidifiers can be incorporated into forced air-heating systems or auxiliary humidifiers can be placed in critical molding areas, and several different types are available. As a last resort there is a no cost method of maintaining plant humidity – simply wet the shop floor periodically during the day. Keeping the floor damp provides a good method of evaporating large quantities of water over a large area. It also helps keep the dust down.

Ionization – Treating the plant air or compressed air from blowguns by ionization can reduce ambient static development, or can be used to treat a local area. For example, blowing off a mold with ionized air will neutralize the surface charge for the moment. This may be used when blowing off dust prior to waxing the mold. However the act of rubbing the mold surface will create a surface charge. This will require the application of ionized blowgun air repeatedly during the waxing procedure. Ionization blowguns are nuclear powered, using Polonium 210 isotopes that have a half-life of about 138 days, so they need to be replaced on a regular basis. The radiation produces by this isotope is not harmful to humans.

Electrostatic discharge is no joke as witnessed by the chopper operator at the boat plant. In this specific case the new combination of a flow chopper – with increased static levels, the non-grounded conductive mold, and the low humidity conspired to cause a near disaster. The fortunate aspect is, “Houston, we have an answer”. By paying attention to these recently discovered aspects of ESD you can avoid potentially hazardous situations.