WALK-THROUGH SURVEY REPORT: STYRENE EXPOSURES DURING FIBER REINFORCED WIND BLADE MANUFACTURING

at

LM Glasfiber

Grand Forks, ND

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Introduction

The National Institute for Occupational Safety and Health (NIOSH) is part of the Centers for Disease Control and Prevention (CDC) in the U.S. Department of Health and Human Services (DHHS). NIOSH was established in 1970 by the Occupational Safety and Health (OSH) Act, at the same time that the Occupational Safety and Health Administration (OSHA) was created in the U.S. Department of Labor (DOL). The OSH Act mandated NIOSH to conduct research and education programs separate from the standard-setting and enforcement functions conducted by OSHA. An important area of NIOSH research involves measures for controlling occupational exposures to potential chemical and physical hazards.

In the early 1980s, NIOSH researchers conducted an engineering control technology assessment of styrene exposures in the fiberglass reinforced plastic (FRP) boat manufacturing industry.[(1)] The study focused mainly on ventilation systems and work practices used in the open molding production of large FRP boats and yachts. In 2004, NIOSH engineers from the Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology (DART) began a follow-up assessment to evaluate worker exposures from new processes that were not necessarily used during the previous NIOSH study. Several of the technologies include processes that use low styrene resins, non-atomizing spray equipment, pressure driven rollers, improved ventilation, and closed molding.

In September of 2007, environmental health and safety representatives from LM Glasfiber contacted NIOSH engineers to request participation in the styrene study. LM Glasfiber is a major wind-blade manufacturer that uses styrene-based resins to manufacture large FRP blades for the rapidly growing utility scale wind energy industry. Due to the similarities in the styrene-based resins and their similarities in the process, NIOSH engineers agreed that workers in a wind-blade manufacturing plant might have similar potential for styrene exposures as workers in boat manufacturing.

On October 19, 2007, NIOSH/EPHB conducted a walk-through survey at LM Glasfiber, in Grand Forks, North Dakota. The primary purpose of this walk-through was to learn more about the FRP wind-blade manufacturing industry and to assess the suitability of this facility for an in-depth survey. The main goals of the walk-through survey were to obtain preliminary information about styrene concentrations in the plant and to observe the engineering exposure-control measures during the wind-blade manufacturing process.

LM Glasfiber manufactures wind-blades using a closed molding process known as vacuum-assisted resin-transfer molding (VARTM). LM Glasfiber is a Danish-owned company that operates on a global basis with twelve locations worldwide. With US wind power growing at a rate of 25-30% per year, LM Glasfiber has plans to open up new facilities to help meet the demands for this form of renewable energy. At the time of the survey, the LM Glasfiber facility in North Dakota was operating four shifts to manufacture wind-blades 24 hours per day, 365 days per year. Approximately 600 of the plant's 940 employees work in areas where they may be potentially exposed to styrene vapor.

Styrene Usage and the Hazards of Exposure to Styrene and Noise

The major chemical component of concern in terms of occupational exposures in the FRP process is styrene. Styrene is a fugitive emission that evaporates from resins, gel-coats, solvents, and surface coatings used in the manufacturing process. The polyester resins used at the LM Glasfiber plant contain between 36 and 42 percent styrene. Styrene is an essential reactive diluent for polyesters because it reduces the viscosity of the polyester mixture making it thinner and more capable of coating fiber reinforcements allowing the reactive sites on the molecules to interact. As an active diluent, styrene will react in the free-radical cross-linking reaction. Cross-linking is the attachment of two chains of polymer molecules by bridges composed of molecular, in this case styrene, and primary chemical bonds. Since styrene is consumed as part of this reaction, there is no need for removal of the diluents after the part is formed. However, if the process is not controlled properly, vapors from the application and curing process may pose an inhalation exposure hazard for workers near the process.

Humans exposed to styrene for short periods of time through inhalation may exhibit irritation of the eyes and mucous membranes, and gastrointestinal effects.[2] Styrene inhalation over longer periods of time may cause central nervous system effects including headache, fatigue, weakness, and depression. Exposure may also damage peripheral nerves and cause changes to the kidneys and blood. Several studies have shown that styrene exposures were linked to central and peripheral neurologic,[3,4,5] optic,[6,7] and irritant[8] effects when occupational exposures to styrene vapors in air were greater than 50 parts per million (ppm). There is also evidence concerning the influence of occupational styrene exposure on sensory nerve conduction indicating that: (1) 5% to 10% reductions can occur after exposure at 100 ppm or more; (2) reduced peripheral nerve conduction velocity and sensory amplitude can occur after styrene exposure at 50 to 100 ppm; (3) slowed reaction time appears to begin after exposures as low as 50 ppm; and, (4) statistically significant loss of color discrimination (dyschromatopsia) may occur.[9] Some other health effects of low-level styrene exposure include ototoxicity in workers and experimental animals. Styrene exposure can cause permanent and progressive damage to the auditory system in rats even after exposure has ceased.[10,11] Styrene has been shown to be a potent ototoxicant by itself, and can have a synergistic effect when presented together with noise or ethanol.[12,13,14,15]

The primary sources of environmental evaluation standards and guidelines for the workplace are: (1) the OSHA Permissible Exposure Limits (PEL);[16] (2) The NIOSH Recommended Exposure Limits (REL);[17] and, (3) the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLV®).[20] Employers are mandated by law to follow the OSHA limits; however, employers are encouraged to follow the most protective criteria. The NIOSH REL for styrene is 50 ppm for a 10-hour time-weighted average (TWA) (meaning the limit applies to the average exposure during a work day of up to 10 hours and a work week of up to 40 hours), with a

15-minute short-term exposure limit (STEL) of 100 ppm, limiting average exposures over any 15-minute period during the work day. [18] These recommendations are based upon reported central nervous system effects and eye and respiratory irritation. The OSHA PEL for styrene is 100 ppm for an 8-hour TWA exposure, with a ceiling limit of 200 ppm.[19] The ceiling limit restricts exposures for any portion of the work day. The ACGIH revised its Threshold Limit Value (TLV®) in 1997, and recommends styrene be controlled to 20 ppm for an 8-hour TWA exposure with a 40 ppm, 15-minute short-term exposure limit (STEL). [20]

Exhaust ventilation, low styrene-content resin, non-atomizing spray equipment, and personal protective equipment have historically been recommended to limit styrene vapor exposures to workers. Recent developments in specific closed molding technologies, however, may also provide protection by reducing process emissions of styrene, and, in turn, the concentration of styrene in the workers' breathing zones.

Facility Description

The LM Glasfiber facility in Grand Forks, North Dakota uses a closed molding method known as vacuum assisted resin transfer molding (VARTM) to manufacture wind-blades. The facility is located on property totaling 540,000 square feet of land area and was purchased by LM Glasfiber in 1999. Manufacturing operations take place in two buildings on the property referred to as the "L" and "M" buildings.

The supply air flow rates from the four air handling units (AHUs) in each of the buildings were provided by facility representatives and are shown in Tables 1 and 2 (in cubic feet of air volume per minute, or CFM).

Table 1: Supply air flow rates for air handling units in the L Building

AHU #	Air Flow Rate (CFM)
1	50,000
2	25,000
3	52,000
4	55,000

Table 2: Supply air flow rates for air handling units in the M Building

AHU #	Air Flow Rate (CFM)
5	55,000
6	55,000
7	44,000
8	44,000

The L Building is split into two sections. Air handling units (AHU) 1, 2, and 3 are located in the large open space on the east side of the L Building and serve the gel-coating and closed molding VARTM areas. AHU #4 serves the remaining portions of the L Building including office areas. The four air handling units in the M Building serve the assembly area on the west side of the building and web cut and trim on the east side of the building. The general ventilation supply air in both buildings consists of fabric sock air distribution systems such as what is shown in Figure 1 for the M Building. The exhaust ventilation system in the cut and trim side of the M Building is shown in Figure 2 and is located on the opposite sides of the blades from the supply. Exhaust vents in the L Building are located in the floor and are shown in Figure 3. The vents in Figure 3 were originally located to be at the ends of the blades, however as product demands have required longer wind-blades, the ends of the blades extend well beyond the location of the vents. Additional exhaust ventilation is located along the south side of the L Building. Each exhaust air system corresponds to the supply-air systems. According to plant representatives, the supply-air flow rate for each system is greater than that of the exhaust air to keep the plant under positive pressure. The supply-air system delivers 100% outside air, heated or cooled as needed, so there is not any recirculation. In both buildings, the exhaust systems only provide dilution ventilation. The only area where local exhaust is used is on the grinding equipment for dust control during cutting, grinding, and sanding.

Figure 1: General ventilation supply in the M Building web cut and trim area

Figure 2: Exhaust ventilation in the web cut and trim area of the M Building

Figure 3: In-floor exhaust ventilation in the L Building

Process Description

The process of designing wind-blades at LM Glasfiber begins with design software such as finite-element analysis to calculate proper aerodynamic and structural requirements. The design then determines the optimal placement of fiber and core materials in the blade. The basic manufacturing process is to use two glass-fiber shells attached to two rigid beams. The rigid beams are called the web which increases the strength of the blade through proper placement. The blades are produced starting with the outside of the blade and works in toward the center. The process begins with the creation of the blades' protective coating by gelcoating the mold, and then works into the structure in this order:[21]

1. Mold prepared
2. Gel-coat sprayed into the mold – creating the protective surface of the blade
3. Glass fiber laid out (supporting layer)
4. Bushings installed
5. Balsa/foam installed
6. Glass fiber laid out over the balsa and bushings

7. Vacuum film placed over glass fiber and balsa

8. Resin infused

9. Vacuum film removed

10. Sandwich web installed

11. Lightning conductor, etc. installed

12. Adhesive applied to edges of the shells and to the webs

13. Shells are bonded

14. Blade removed from mold and given final finish (cutting and grinding).

The fiberglass blades are built from glass-fiber reinforcements placed in a mold and saturated with a polyester resin. The resin hardens to form a rigid part reinforced with the fiberglass. The gel-coating process starts when the mold is sprayed with a layer of gel-coat, which is a pigmented polyester resin that hardens and becomes the smooth outside surface of the part. During the gel-coating process, the worker walks along the concave side of the mold while spraying the gel-coat. The lamination process begins with the placement of the fibers and core material before placement of vacuum film for resin infusion. The blades are laminated in two shells before the sandwich web is installed, adhesive is applied to the edges of the shell and web, and one shell is moved with a crane and fixed to the other half to assemble the blade. The blade is then removed from the mold for cutting of the outside edge and grinding and sanding to provide a smooth finish.

Closed molding

Closed molding typically refers to a manufacturing process that uses 1) two rigid half molds (male and female) between which composite parts are produced when these molds are closed; or 2) a solid mold (female) and a flexible film such as a silicone sheet or bag that is placed on top of the resin/fiberglass composite. Recent advances in mold development methods which use two flexible molds, or a flexible mold and a flexible film are also considered variations of closed molding.

There are two closed molding core technologies that are used in manufacturing FRP; Resin Transfer Molding (RTM) and Vacuum Infusion Processing (VIP). To distinguish the two methods, RTM is a pressure-driven process whereby resin is injected into a closed-mold cavity at higher than atmospheric pressure. VIP is a vacuum-driven process where resin is pulled into the mold cavity which is lower than atmospheric pressure. There are a number of variations and combinations of these core technologies. For example, pressure-injection RTM can be combined with vacuum assist in a process known as vacuum-assisted resin-transfer molding (VARTM). Likewise, the vacuum infusion process can use low-pressure injection assist and is known as pressure-assisted vacuum-infusion processing.

The technology used at LM Glasfiber is VARTM. Compared to open molding, it is expected that the closed molding technology should significantly reduce environmental emissions and worker exposure to styrene. However, the gel-coating portion of the process is presently still performed in an open mold.

Results

NIOSH engineers did not collect styrene vapor, noise, or dust measurements during this walk-through survey. However, the environmental health and safety representatives from the plant provided styrene vapor, dust and sound-level data from several operations to assist NIOSH engineers in planning an in-depth evaluation. The personal breathing zone measurements of styrene in air provided by the company were collected by Performance Based Safety LLC, Nixa, MO. The samples were collected using model 3500 3M organic vapor monitors. The monitors each use a single charcoal sorbent wafer to collect organic vapors. Analysis was performed by Analytics Corporation in Ashland, VA using NIOSH method 1501. The personal air samples measurements for styrene generally ranged from 9 ppm to 26 ppm. The sound-level data provided by the company was also collected by Performance Based Safety. The samples were collected using a Quest Q-300 noise dosimeter which recorded levels near 70 dBA or less in most areas of the plant with some levels around 90 dBA near grinding operations in the M Building. The company also provided sampling results for total dust and respirable dust which indicated some workers performing grinding operations may be in areas of high dust exposure. However, changes in local exhaust on grinding equipment may have reduced exposures after the data was collected. Workers near areas where potential dust inhalation hazards are present wear 6000 series 3M respirators with organic vapor and P100 HEPA cartridges in series.

Preliminary Conclusions and Recommendations

All of the personal breathing-zone and area air styrene measurements provided by the company were below the OSHA PEL of 100 ppm and NIOSH REL of 50 ppm. However, none of the measurements provided were from workers inside the confined space of the blade. Environmental health and safety representatives mentioned that it would be beneficial for NIOSH to conduct further research on evaluation and control of worker exposures to styrene vapor inside of the blade as well as other areas of the plant. At the time of the evaluation, NIOSH engineers were also interested in further evaluation of worker exposure to styrene vapor from the VARTM process since it is expected that the closed-mold lamination portion of the process would have lower occupational exposures than traditional open molding.

The continued use of the organic-vapor charcoal-filter respirators with P100 HEPA dust filters is highly recommended especially for those workers in the M Building. The ventilation systems installed seem to be working properly. The provided sound-level data indicated that workers performing grinding operations should continue to be enrolled in a hearing conservation program. Following this walk-through evaluation, NIOSH engineers determined that styrene vapor-control research opportunities at the wind-blade manufacturing facility align with the goals for the NIOSH styrene research project.

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