Glass Fiber Manufacturing and Fiber Safety: the Producer’s Perspective

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Historically, the potential health effects of airborne fibers have been associated with the dose, dimension, and durability. Increasing focus is being placed on the latter category. Concern about airborne fiber safety could be reduced by manufacturing fibers that are not respirable; however, due to performance and manufacturing constraints on glasswool insulations, this is not possible today. These products are an important part of today’s economy and as a major manufacturer, Owens-Corning is committed to producing and marketing materials that are both safe and effective in their intended use. To this end, manufacturing technology seeks to produce materials that generate low concentrations of airborne fibers, thus minimizing exposure and irritation. The range of fiber diameters is controlled to assure effective product performance and, as far as possible, to minimize respirability. Glass compositions are designed to allow effective fiber forming and ultimate product function. Fiber dissolution is primarily a function of composition; this too, can be controlled within certain constraints. Coupled with these broad parameters is an extensive product stewardship program to assure the safety of these materials. This article will discuss the factors that influence glasswool insulation production, use, and safety.

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Introduction

Owens-Corning has produced glass fiber-based materials for over 50 years. Glass fiber-based products play an important role in today’s economy. Over 30,000 products have been made that consist of or utilize glass fibers. Glass fiber-based insulations play a significant role in protecting the environment. For example, in the United States alone, the use of glass fiber insulation saves energy equivalent to over 4 billion barrels of oil annually. Product safety should be of overriding importance to any manufacturer. For Owens-Corning, safety in the manufacturing and use of glass fibers is appropriately an important issue.

Knowledge of the health effects of exposure to asbestos fibers has led to a great deal of research to elucidate the actual mechanisms by which some types of airborne fibers produce disease. Currently, there is intense interest in the role of durability or biopersistence in the biological activity of airborne fibers.

This article briefly reviews what are believed to be important determinants of the biological activity of fibers as those determinants relate to production and use of the fibers. Additionally, it will point out some areas of uncertainty regarding fiber characteristics that require additional research. Finally, it will discuss the responsibility of the producers of fibers in assuring the safety of their products.

Fiber Characteristics Associated with Health Effects

The three major characteristics of fibers that have received general acceptance as being strongly related to their biological activity are dose or airborne concentration; physical dimensions of the fibers; and the durability, or more appropriately, the biopersistence of fibers within the lung.

Airborne Fiber Exposures

It is only within the last 20 years that techniques to assess the actual concentration of airborne fibers have come into widespread use. Typically, using microscopic counting techniques, these methods attempt to quantitate fibers considered to be respirable, i.e., less than 3 mm in diameter and greater than 5 mm in length. These fiber-counting methods (1,2) provide a great deal of information on past and current airborne fiber concentrations.

It is known that historic exposures to airborne asbestos were in the tens, hundreds, and occasionally thousands of fibers per cubic centimeter (f/cc) (3). In marked contrast, airborne concentrations of glass fibers are much lower (Figure 1), generally, 1.0 f/cc (4). Additionally, some studies suggest that historic exposures were probably similar (5). There are a variety of reasons for the low levels of airborne glass fibers generally seen in the manufacture and use of these materials. For example, typical glasswool insulation fibers (by far the predominant form of glass fibers in commerce) tend to have nominal diameters of the order of 3 to 10 mm (6). The larger dimensions of glasswool products coupled with higher densities result in much higher settling velocities if they become airborne.

In addition to larger diameter, most glass fiber insulation products incorporate binders to improve product performance. The use of binders also tends to reduce airborne fibers associated with product use.

Fiber Dimension

The pioneering work of Stanton and Pott has shown that fiber size plays a significant role in the biological activity of fibers (7,8). Early studies indicated that fibers less than 1 mm in diameter and greater than 8 mm in length possessed the greatest potential for tumor induction when placed in high quantities directly at the target mesothelial tissue. What is not clear is whether these results are applicable to inhaled fibers. As pointed out in a recent World Health Organization Conference on relevance of animal models (9), even if tumors are produced by intracavitary injection or implantation, it must be determined whether inhaled fibers can reach the mesothelium in a sufficiently unmodified state and in sufficient quantities to allow this tumorigenic potential to be expressed. Certain glass fiber compositions, for example, are active in the intraperitoneal (IP) test, yet, they have not produced disease in man nor in experimental animals following inhalation.
These contrasting results must be examined for their relevance to fiber safety in man. Fiber producers must rely on animal bioassays that are both relevant and predictive of possible human exposures.

For airborne materials, the bioassays should most appropriately utilize the inhalation route of exposure, which is the only relevant route of human exposure. In the case of fibers, the test animals should be exposed to fibers that are representative of the size of airborne fibers associated with the manufacture and use of the product.

From the producer's standpoint, it is not clear which dimensional category of respirable fibers presents more or less biological potential, and efforts should continue to control exposure to airborne fibers.

The Role of Fiber Durability

Stanton was the first to suggest that durability of fibers might play a role in their biological activity. Since his report (7), increasing interest in the role of fiber durability has led to significant new research. Based on the concept of durability, the actual dissolution rate of fibers in physiological solutions is now routinely measured in vitro. Research is also underway to link the dissolution rate of fibers measured in vitro to their behavior in vivo. Finally, it is becoming clear that biopersistence of fibers within the lung is a complex phenomenon consisting of multiple components. These include the normal, enhanced, or overloaded clearance processes of the lung; size of the inhaled fibers (particularly as length relates to the dimensions of the alveolar macrophage); dissolution rate of inhaled fiber at neutral and acidic pH; and mechanical properties of intact and digested fibers.

Glasswool fibers may be manufactured with a range of compositions, and it is known that glass composition has a significant influence on in vitro fiber dissolution rates (10). In vitro studies suggest that most glasswool fibers dissolve much more rapidly than chrysotile (11) at neutral pH. At acidic pH, such as is thought to exist within the phagolysosome, glass fibers are considerably more stable than they are at neutral pH. In vivo studies of glass fibers have found that long glass fibers dissolve faster than short ones. This observation is consistent with the known dissolution rate of glasswool fibers in vitro at different pHs. As such, it appears that in vitro dissolution rate is related to in vivo behavior of fibers, but the relationship may not be simple.

Glass fiber composition is dictated by both process and product constraints. From a process standpoint, forming and fiberizing constraints dictate the range of glass compositions that can be used in insulation fiber manufacturing. In a similar fashion, product requirements also constrain glass composition. For example, glasswool must pass water corrosion tests as well as tests for recovery after compression and insulation effectiveness. Table 1 gives the major components of glasswool fibers, their role in production and product properties, and their influence on in vitro fiber dissolution rates.

A useful overview of glass fiber composition and production can be found in Man-made Vitreous Fibers, Nomenclature, Chemistry and Physical Properties (6). While the role of durability is becoming better understood, a number of uncertainties regarding the measurement and significance of fiber durability remain. These include: How should fiber durability be measured? Do in vitro measurements predict in vivo behavior? How does fiber durability relate to fiber biopersistence? How does chemical leaching affect the physical and biological properties of fibers? Is there any relation between pulmonary biopersistence and biopersistence in serosal spaces? Dissolution is a chemical process that proceeds in real time. For example, a fiber that dissolves in 1 year in a rat lung should dissolve in 1 year in a human lung. However, in physiologic time, 1 year is about 1/3 of a rat's lifespan, yet only about 1 to 2% of a human lifespan. Is the biological activity of a fiber related to its ability to persist for a fixed period such as 1 year, or must it per-

Table 1. Typical glasswool compositions: major components in typical insulation glasswools.*

| Chemical component | % Composition | Function |
|--------------------|--------------|---------|
| SiO₂               | 55–70        | Provides major structural backbone of glass fiber; little influence on in vitro dissolution rate |
| A1₂O₃              | 0–7          | Improves corrosion resistance and water durability; markedly decreases in vitro dissolution rate |
| CaO                | 5–13         | Interchangeable; reduces melting temperature of batch |
| MgO                | 0–5          | Significantly increases in vitro dissolution rate |
| Na₂O               | 13–18        | Interchangeable; reduces melting temperature of batch |
| K₂O                | 0–2.5        | Increases in vitro dissolution rate |
| B₂O₃               | 3–12         | Reduces melting temperatures of the glass |

*A variety of minor components may also be present.
sist for a fraction of the lifespan of the species?
When answers to these questions become available, the significance of the role of fiber durability in the biopersistence and biological activity of respirable fibers will be better understood.

**Glass Fiber Safety**

An extensive database has accumulated over the last 50 years regarding the health and safety aspects of glass fibers. Extensive information is available on exposures, morbidity, and mortality studies of exposed workers; multiple chronic inhalation studies; and results from a variety of implantation studies in animals. These results are consistent in showing low exposures. They show no causal relationship between exposure to inhaled glass fibers and malignant or nonmalignant disease. Animal inhalation studies with a variety of glass fibers at thousands of times human exposure levels are consistently negative for fibrosis and malignant disease. In contrast, intracavitary injection of certain glass fibers has been shown to induce tumors.

With this extensive research, much of which was supported by the glass fiber industry, the industry is confident of the safety of its products. This database has led to the development of sound work practices, and recommendations regarding product handling have been communicated to the people who use these materials. The glass fiber industry continues to support health-related research and to provide communication of these results.

**Safety Assessment of New Fibers**

Due to more recent development or to limited production, most other fiber families in use or under development do not have the extensive body of health and safety research that exists for glass fibers. In the absence of extensive research, how can the safety of new or untested fibers be assessed, if they are outside the range of dissolution rates for vitreous fibers that have been tested in chronic inhalation studies? One possible procedure would be as follows.

Given the known biological activity of some fiber types and a lack of clear understanding of all the factors responsible for this activity, exposure to untested new fibers should be minimized.

Initially, the nature of the fiber—its size, physical structure, and chemical durability—are important characteristics that can be readily obtained; and, when compared with knowledge of other fiber types, they give insight on possible health effects.

If a new fiber appears to have commercial potential, a limited animal inhalation study, for example, a subchronic study followed by 60- to 90-day observation, could provide important evidence on fiberogenic potential and biopersistence of the fiber. This should be a multidose study with at least one dose in the hundreds of fibers/cc range. If little or no fibrogenic potential is evident for this test, test marketing and limited production could proceed with a provisional exposure limit established at 1.0 fibers/cc.

If, following test marketing, the fiber still has economic potential, a long-term animal inhalation study should be performed. This study could be patterned after the ongoing studies on man-made vitreous fibers and include parameters such as multiple doses, lung fiber burden determination, and interim sacrifices. If the study is negative for tumorigenesis or fibrosis, exposure should be limited to 1.0 fibers/cc, as has been proposed for glass fibers. If results of the inhalation study are positive for tumor formation or significant fibrosis, further evaluation and a possible reduction in the 1.0 fibers/cc exposure limit would be warranted.

This concept would lead to the establishment of a provisional exposure limit for respirable fibers of 1.0 fibers/cc for those fibers with negative findings in a well-conducted short-term inhalation study. A general standard of 1.0 fibers/cc fiber would apply to all respirable fibers unless the results of a well-conducted chronic inhalation study indicated a need for a lower standard.

In today’s workplaces, the 1.0 fibers/cc standard is achievable by engineering controls. Where engineering controls are not feasible, respiratory protection is essential.

Until the actual mechanisms of fiber toxicity are elucidated, we will have to rely on the results of the well-conducted chronic inhalation assays to provide evidence of practical fiber safety when exposures are controlled. By conducting the inhalation study at concentrations that include a dose of 100 to 300 times the 1.0 fibers/cc standard, as are being used in the ongoing studies at the Research and Consulting Center, Geneva, we can provide a practical 100-fold safety factor for the use of these fibrous materials.

**Conclusion**

Given the important role and ubiquitous nature of fibers in our world today, it is not possible to create a fiber-free environment, nor is it necessary. What is necessary is that we produce and use fibers in a responsible manner. We must continue to study fibers to determine the properties that may be associated with biological activity, and determine the potential effects of inhalation of new fibers. We should work to keep possible exposure to respirable fibers to levels that will not cause disease. Finally, we must communicate information on the health and safety aspects of fibers to people who will manufacture and use fiber-containing products.

Collectively, these responsibilities are encompassed under product stewardship (Figure 2). While Owens-Corning is making substantial progress in understanding the life cycle of its products, we have much to learn about the biological potential of these fibers.
fibers, as well as understanding risk assessment and risk management. However, product stewardship remains our cornerstone in managing these uncertainties. The International Agency for Research on Cancer has provided a forum that allows us to combine knowledge. Industry, government, academe, and labor all stand to benefit from this open dialogue, as does the public. The success of our product stewardship effort depends on our ability to sustain this partnership in shared learning.

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