The Seven Foundations of High-Containment Facilities

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Introduction

Critical and high-containment environments, such as those used in the pharmaceutical, nutraceutical, healthcare, vivarium animal care, food and beverage, and biosafety industries, are some of the most strictly-regulated facilities in the world. It is crucial that, even under the harshest conditions, they retain structural integrity and remain impermeable to contaminants in order to protect its occupants and the surrounding community.

We have outlined Seven Foundations of High-Containment Facilities that should be taken into consideration when building or updating critical environments: 1) mechanical properties, 2) physical properties, 3) fire and smoke development, 4) barrier performance, 5) colorfastness, 6) compliance, and 7) constructability. In this paper, we will address the importance of the characteristics that comprise each of these seven foundations as well as the significance of Arcoplast's performance.

Figure 1: Seven Foundations of High-Containment Facilities

Mechanical Properties

The most significant mechanical properties of high-containment environments are those that contribute to the structural integrity of the facility, including joint peel strength, seismic shear strength, pull-out strength, and partition load-bearing strength.
Joint peel strength is defined as "the average load per unit width of bondline required to separate progressively a flexible member from a rigid member or another flexible member." This measurement evaluates the resistance of the joint and/or adhesive to localized stress. *Shear strength*, on the other hand, is "the magnitude of shear stress that a structure can sustain." This kind of stress results from "applied forces that tend to cause adjacent planes of a body to slide parallel in opposite directions," as is often the case in seismic activity. *Pull-out strength* refers to the amount of "force required to pull a bolt out of its foundation." Lastly, *partition load-bearing strength* corresponds to the amount of weight a partition can bear vertically in addition to its own weight.

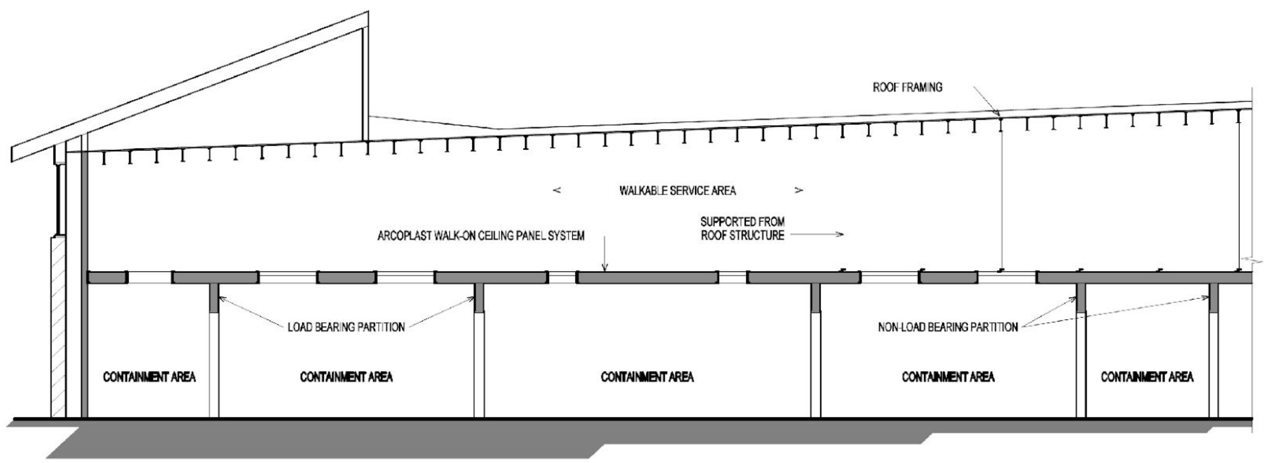


Figure 2: load-bearing partition

All of these qualities evaluate a structure's resilience when acted upon by external forces. Insufficient joint peel strength or shear strength could result in the leakage of hazardous materials into the external environment or the exposure of the sensitive internal environment to contaminants from the external environment. Furthermore, insufficient pull-out strength or partition load-bearing strength could result in collapse, injuring personnel or test subjects and destroying valuable equipment. Utilizing an inferior product may be cost-effective in the short term; however, in the long run, investing in a higher quality product will save both time and money.

Comprehensive structural strength is essential to the integrity and longevity of critical environments. The Arcoplast Gel Coat Fiberglass Reinforced (GFRP) and another remarkable product such as the Acryloyl engineered polymer boasts a joint peel strength of 92.78 lbf (pound-force per inch sample), a spline joint assembly has a seismic shear strength of 380 lbf per inch sample, a corner section assembly has a seismic shear strength of 791 lbf (Figure 3), and a solid panel has a seismic shear strength of 629 lbf (Figure 4) and a pull-out strength of 733 lbs. Arcoplast panel systems have also passed partition load-bearing, walk-on ceiling system load, and seismic loading compliance tests.

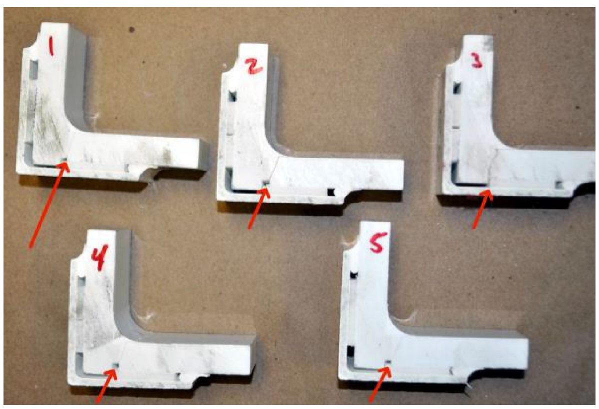


Figure 3a: photo of corner section assembly

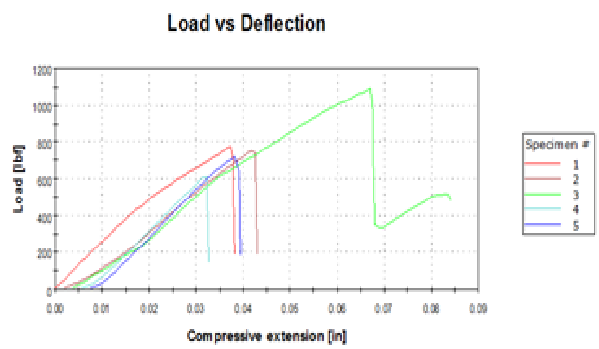


Figure 3b: corner section assembly load vs deflection graph

Seismic Shear Strength Test

Figure 3a: photo of solid panel seismic shear test

Specimen #	Max Load (lbf)	Compressive Extension @ Max Load (in)
1	580.4	0.067
2	622.2	0.062
3	603.3	0.062
4	684.8	0.076
5	655.8	0.053
Average	629.3	0.064

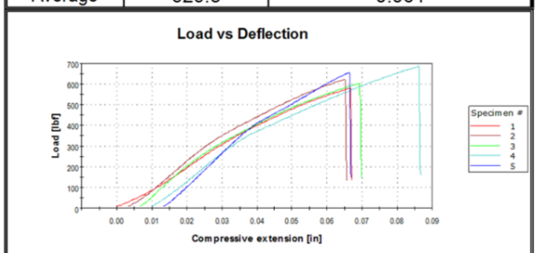


Figure 3b: solid panel load vs deflection graph

Physical Properties

The structural material's physical properties can significantly influence the internal environment of a high-containment facility. These properties include qualities that affect the senses, such as sound and light. Sound absorption is the reduction in intensity of sound as the energy of the sound wave is converted into heat energy. Sound transmission loss is the reduction in intensity of sound as it passes through a wall or other structure. These qualities are important for the wellbeing of animal subjects because loudness can cause fear and anxiety in animals. It is also important to maintain a relatively quiet working environment for humans, as loudness has been found to decrease productivity in the workspace.

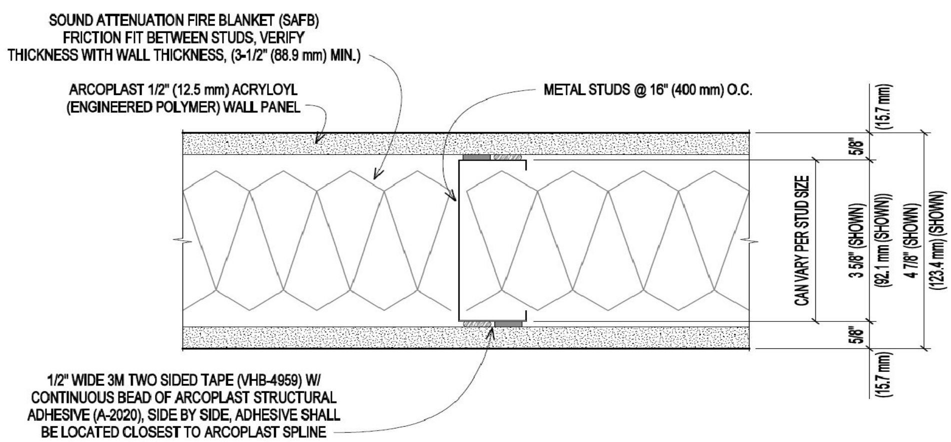
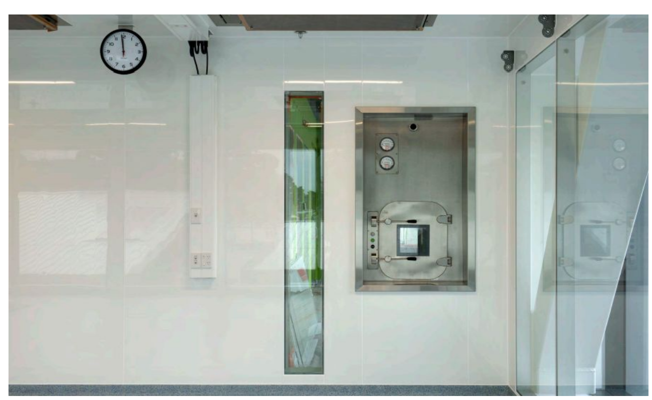


Figure 4: Arcoplast ½" wall panel partition construction detail

A Sound Transmission Class (STC) of 57 for the ⅜" (9.5mm) GFRP panel and the (STC) of 59 is achieved with an Arcoplast ½" (12.5mm) wall panel, as shown in this typical partition construction detail (Figure 4). Meanwhile comparatively, a 5/8" drywall panel with the same partition construction detail would result in an STC of 49, a significant difference when considering the design of wall partitions in animal housing facilities. Similarly, specular gloss contributes to a more luminous environment, which is associated with increased worker productivity. High degrees of light reflection also mean that fewer light fixtures are needed to illuminate the



space, saving money and energy as well as reducing the number of penetrations into the ceiling.

Figure 5: photo of high-gloss Arcoplast panel

When constructing a critical environment, it is also important to consider factors like impact resistance, hardness, flexibility, compressive strength, and tensile strength. Surfaces in these environments must be able to withstand frequent, vigorous, often high-pressure washdown and decontamination procedures. They must resist the scratches and indentations associated with everyday tasks as well as the natural processes that result in compressive and tensile forces, such as erosion and seismic activity. In physically abusive environments, the finish substrates used for cladding walls and partitions is extremely important when one considers that a drywall panel has a compressive strength of only 350 psi, while Arcoplast GFRP composite panels have a compressive strength of up to 16,500 psi and the Acryloyl engineered polymer has a compressive strength of up to 14,000 psi. This difference is critical in the selection of highly impact-resistant products.

Specific labs also engage in high-temperature procedures, it is also important that the material is not compromised by extreme variable temperature, making heat deflection temperature, coefficient of linear thermal expansion, and thermal conductivity crucial factors in the material selection process.

Moisture is another threat to critical environments. The construction material must be impermeable to water and water vapor transmission, which can contribute to the growth of mold, fungi, algae, and bacteria. Similarly, surfaces must be smooth and non-porous to prevent the growth of microorganisms in pockets where moisture can collect. These microorganisms can compromise sterile environments, contaminate equipment and products, and cause infections in animal subjects as well as in humans. In addition to being smooth, non-porous, and impermeable to water and water permience, Arcoplast GFRP and Acryloyl engineered polymer's have inherent antimicrobial properties, eliminating the risk of surface anomalies caused by moisture or particulates during application.

Fire & Smoke Development

As previously mentioned, it is important to consider a material's tendency to warp when exposed to high temperatures when constructing a critical environment. However, it is even more important to consider how the material reacts in terms of fire and smoke development. A distorted surface will result in costly repairs, but fires and toxic smoke products could result in loss of life. For use in a critical environment, a material should have flame-retardant properties, smoke-suppressant properties, and low toxicity of thermal decomposition products.

Results from the tests that evaluate these properties can be misleading because manufacturers are only required to test the *surface* material, not the entire panel assembly. The Arcoplast GFRP and Acryloyl engineered panels were tested in their entirety under a variety of conditions, including full-scale room fires, to assess reaction to fire performance. These tests determined that Arcoplast's product exceeds flame-retardant, smoke suppressant, and decomposition product toxicity requirements. Moreover, Arcoplast GRRP and Acryloyl panels exceeds the Building Code of New York's stringent requirements for lethal toxic potency of thermal decomposition products, which mandate that materials must be "not more toxic than wood" under thermal decomposition.

Barrier Performance

Even in the absence of mechanical, physical, and chemical stressors that affect impermeability or structural integrity, a critical environment can be compromised by leakage of air into or out of the room. In a laboratory, this could mean dangerous fumes leaking into less secure parts of a facility. Conversely, in a factory, it could result in external contaminants tainting food products. It is therefore crucial that these environments are built in such a way that maximizes barrier performance, from the largest doors to the smallest screw penetrations.

High-performance barrier systems are especially important in the wake of the COVID-19 pandemic, which has proven that healthcare facilities in even the most developed countries are not sufficiently equipped to contain highly-infectious diseases. Faulty barriers could expose workers or patients on both sides of the high-containment environment to airborne or aerosolized pathogens, increasing the risk of contagion.

Barrier performance is generally assessed by measuring air pressure decay, supplemental helium leakage, and window panel pressure decay. Any drop in pressure over time is indicative of a leak, which could potentially endanger the health and/or operations of an entire facility. Arcoplast GFRP and Acryloyl engineered polymer panels function especially well in this capacity, passing air pressure decay tests for nuclear air treatment systems, small chamber BSL's, accessories relating to MEP, screw penetrations, expansion joint and

electrical face plates, and window panels. The ability to incorporate windows into high-containment rooms is a significant, novel development that will be discussed later.

Figure 6: Arcoplast panel system featuring outside-facing windows

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Colorfastness

When constructing a critical environment, colorfastness may not be one of your top priorities; however, it can be just as important as some other properties. Cleanrooms and other high-containment environments must be vigorously sanitized and decontaminated with harsh chemicals on a regular basis, sometimes multiple times per day. Over time, decontamination with formaldehyde gas, hydrogen peroxide vapor, chlorine dioxide, and other substances can discolor surfaces. This effect is compounded by other sources of discoloration, such as ultraviolet light exposure and chemical reactions. Unsightly stains can make the entire workspace appear unprofessional, which could potentially result in lost business. Furthermore, stains can negatively impact the degree to which light is reflected by the surface, creating a need for additional light sources that would not have otherwise been necessary.

Arcoplast panels exhibit extraordinary colorfastness, resisting discoloration by formaldehyde gas, hydrogen peroxide vapor, and chlorine dioxide decontamination procedures as well as alkaline and chlorinated sanitation procedures. The surface and Bio-Seal sealant materials are chemically compatible, ensuring that one does not discolor the other. Combined, the stain resistance and cleanability of these panels allow critical environments to endure decades of harsh use without compromising functionality or professional appearance.

Compliance

Due to the nature of the work that takes place in high-containment facilities, many government agencies and health organizations have implemented strict regulations for their construction. In the United States alone, they must meet the requirements set by the United States Department of Agriculture (USDA), the Food and Drug Administration (FDA), the National Institutes of Health (NIH), the Centers for Disease Control and Prevention (CDC), the National Institute of Allergy and Infectious Diseases (NIAID), and the World Health Organization (WHO), in addition to any state- or city-specific agencies, such as the City of New York Department of Buildings.

Arcoplast panels meet and exceed the requirements set by the WHO, USDA, FDA, NIH, CDC, NIAID, Canada Agriculture, and the City of New York Department of Buildings. To be compliant with the City of New York Department of Buildings, the construction material must be “not more toxic than wood.” Arcoplast GFRP and Acryloyl polymer panels even meet the demands of the Living Building Challenge 3.1, described as "the most rigorous green building standard ever," which requires buildings to not be constructed with any of over 800 potentially dangerous chemicals.

Until recently, it has been extremely difficult to introduce outside-facing windows into cleanrooms while maintaining compliance with the standards set forth by regulatory agencies. However, due to advances in engineering and constructibility, it is now possible to integrate windows into these environments using Arcoplast panel systems. The natural lighting provided by outside-facing windows reduces the number of light fixtures (and ceiling penetrations) necessary in the room as well as increases worker health and productivity by eliminating the "bunker mentality" associated with working in windowless, bunker-like laboratories.

Figure 7: Arcoplast panel system featuring a large, outside-facing window

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Constructability

When building or retrofitting cleanrooms for high containment facilities, it is important to consider the constructability of the product(s) in use in every step of construction, from design concept to final commissioning. Constructability is the concept used by various metrics to provide the synchronized blueprint execution for cost management and project commissioning. If done properly, it will deliver expected engineering performances with a high level of outcome predictability.

What type of application process does the material require? Does the material allow for curved or custom applications? Can windows be easily incorporated into the design? How many products are necessary to achieve the end goal? How long will the various steps of the construction process take? These are a few examples of important constructability issues that are often overlooked in the initial phases of cleanroom design.

Arcoplast premanufactured panels exhibit a level of constructability unmatched by competitors. Because premanufactured panels utilize a dry application process, no water is necessary, thereby reducing the risk of introducing contaminants into the cleanroom environment during the construction or retrofitting process as well as eliminating the risk of creating anomalies in surface texture typical of wet construction processes. This also allows high containment environments to be constructed in remote areas with limited access to water. The GFRP panels can be molded and the Acryloyl panels are thermoformable, meaning that high heat can be safely applied to make them temporarily malleable: this is ideal for curved or custom applications that would not otherwise be possible. Outside-facing windows are also possible as a result of Arcoplast's unique constructability. These critical features can only be achieved with products that are well-designed, well-engineered, and fully certified.

The pre-manufactured, non-progressive nature of Arcoplast constructive processes results in significant cost and time savings by minimizing the number of products, time, and labor necessary for on-site construction; reducing susceptibility to environmental influences and project interruptions; and adapting easily to changes to the installation schedule.

For both new and retrofit construction, constructability is especially important in the early pre-design stage when evaluating architectural interior finishes in relation to the product's features, benefits, and potential shortcomings. The product's capabilities/limitations and applications should be reflected in the product's technical bulletins, commercial brochures, websites, white papers, test reports, and certifications. Technical support, quality assurance programs, and a reference list of executed projects are essential prerequisites when selecting critical systems for cleanrooms in high containment facilities.

A qualified, well-engineered wall and ceiling panel system will deliver a predictable outcome. This outcome, as well as design, timeline, and budget compliance, can be ensured by a full-scale mockup. A full-scale mockup facilitates design and engineering by putting into perspective every aspect of the lab, including the initial framework; room dimensions and forms; wall, ceiling and floor finishes; VLADS command console, lighting, equipment, and furniture lay-out; and doors, windows, MEP's, monitoring and security device interface.

Designers, architects, and engineers must also consider another aspect of a product's constructability: the availability of experienced contractors, qualified craftsmen, and access to training/certification programs for project-specific applications. Project site requirements, site preparedness, and access to resources all require careful evaluation, especially when selecting large dimensional wall and ceiling liner panels. Products selected with proven track records, quality inspection programs, and validated test reports significantly diminish the risk factors and greatly increase project efficacies in both time and money as well as provide sustainable expected and extended life performances, no matter where in the world they are constructed.

Conclusion

Critical and high-containment environments are some of the most strictly-regulated facilities in the world. We rely upon high-containment cleanrooms to contain potentially infectious diseases in hospital isolation rooms; study dangerous pathogens in vivarium animal care and biosafety laboratories; and prevent contamination of food, beverages, drugs, and vitamins in factories. It is crucial that, even under the harshest conditions, they retain structural integrity and remain impermeable to contaminants. For these reasons, the Seven Foundations of High-Containment Facilities (mechanical properties, physical properties, fire and smoke development, barrier performance, colorfastness, compliance, and constructability) should be taken into consideration when building or updating critical environments in order to protect its occupants and the surrounding community.