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When engineering an exterior door for long term survival in a high-traffic, high abuse environment, such as today's schools, a counterintuitive approach to door design focused on reduced weight and flexibility has proven effective.

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Doors cannot be considered in isolation. They are just one element in a total system that must work together to avoid maintenance issues and provide the longest possible service life.

Testing Proves the Principles

BY DAN DEPTA

A Counterintuitive Approach to Heavy-Duty Door Design

IF YOU WERE TO DESCRIBE AN exterior door strong enough to withstand a hurricane, a violent explosion, or millions and millions of abusive open/close cycles, what type of adjectives would come to mind? Is that door rigid and heavy? Massive and imposing like a bank vault door? Or would you think the opposite, that a lightweight and flexible door would be best?

As it turns out, for many applications, the most durable, longest-lasting door is a lightweight and flexible door.

Exterior doors are subjected to bending and twisting forces with every open/close cycle, and countless cycles of expansion/contraction due to temperature changes, to say nothing of the forces induced by deliberate abuse. Instead of fighting a losing battle against these forces, why not design the door with the ability to accommodate them and bounce back without sustaining damage?

Long-term survival of exterior entrances in any high-traffic, high-abuse environment, like today's schools, requires an appreciation for the fact that the entrance is a system of interdependent components that must all work together to deliver longer life and reduced maintenance. And it also requires an appreciation of the fundamental laws of motion that pertain to swinging doors, and the inherent physical properties of the materials used to construct the doors.

It's a Simple Matter of Physics

Newton's First Law of Motion deals with the concept of inertia, which, simply stated, is the difficulty you have in changing an object's state of motion. Inertia is directly related to the mass of the object. In other words, a door that is twice as heavy as another door takes twice the effort to open, and twice the effort to stop once swinging. That's bad news for the hardware, which will have to work twice as hard to control this heavier door, and for the framing, too, which has to support that extra weight.

Newton's Second Law of Motion deals with force and how it increases with mass. The implication for entrance service life is that as door mass increases, the forces transmitted into the hardware and framing increase proportionally. The net result of these two immutable laws of nature is that the heavier a door leaf becomes, the more it beats the life out of the hardware and framing components. Doors with less mass are easier to open and transmit smaller forces into the rest of the entrance system, reducing wear and tear. But that's only half of the story. The other half has to do with compliance and elasticity, two properties of materials and structures which have profound implications for total entrance system life.

Designing for Flexural Strength

The counterintuitive approach to designing heavy-duty doors is to design for what is known as flexural strength, rather than rigidity. To build a door with optimal flexural strength, careful attention must be paid to the size and shape of all door components, the materials used, and the methods of fabrication. The stiles and rails tubes must be sized to flex at a rate compatible with the flexibility of the bonded face sheet/foam core system. The core material itself must be foamed in place and have sufficient shear strength and adhesion to bond all door components together into a single integral unit. Face sheets must be secured on all four sides by reglets in the stiles and rails so stress loads can be shared evenly between the perimeter frame and skin/core system, without concentrating at a few screw locations as can occur with applied capping.

Stresses tend to concentrate at the corners of a door, as evidenced by buckling, splitting or "witness marks" in the finish of a door that is beginning to fail. Mitered corner joints secured by corner clips and full-width tie rods are essential to allow adequate elasticity without the permanent deformation or progressive metal fatigue that plague mechanically-fastened or welded corners. A 3/8-inch steel tie rod can comply elastically, much like a spring, to allow repeated deflection without deformation.

When doors are designed for reduced weight and optimal flexibility, all entrance components benefit. This apparent contradiction of conventional wisdom has been proven out by the extraordinary performance and longevity of a unique hybrid door design which combines modern composite materials with aluminum extrusions to produce a flush door that is particularly well-suited to the most demanding exterior applications.

Testing Proves Out the Light and Flexible Philosophy

We started with the ANSI A250.4 Test Procedure and Acceptance Criteria for Physical Endurance for Steel Doors and Hardware Reinforcings test protocol which can simulate real-world operation at an accelerated pace. The lightweight test door was opened and closed every 13.5 seconds every hour of every day for more than four years and reached an incredible 25 million cycles. Despite the equivalent of many lifetimes of use, the door was still performing beautifully and looked like new. Clearly, this test was not hard enough; we needed something tougher.

Next we tried the Window & Door Manufacturers Association NWWDA T.M. 7-90 Cycle Slam Test. Under this protocol, the door starts at a full closed position, is opened to 60 degrees, and then slammed closed, every four seconds. This severe cycle test reveals the effects that prolonged hard use can have on the door and door hardware. When we tested the same type of lightweight composite door, there was no hinge separation or damage to the door after a total of 5 million cycles, representative of more than a lifetime of severe use.

Securing the building is one of the primary functions of exterior doors, and with forced entry a major concern today, we also tested the door in that regard. The ASTM F476 test protocol measures a door assembly's ability to resist, delay, and frustrate certain kinds of forced entry. The lightweight door earned its highest rating.

Hurricanes are a fact of life in some parts of the country, and the role that maintaining entrance integrity plays in protecting structures has been clearly demonstrated by

This lightweight, flexible FRP door was tested for structural strength by repeatedly slamming it with a bag filled with 215 pounds of sand. The distance was increased incrementally until it reached a force of 750 ft-lb.

recent storm events. A pair of lightweight composite doors were tested to Florida Building Protocols TAS 201 (impact test), 202 (uniform test) and 203 (cyclic wind pressure loading test). The cyclical loading portion of the test subjects the entrance to thousands of positive and negative pressure loadings that flex the doors, which refused to yield. The large missle impact portion of the test involves firing a nine pound 2 x 4 at the door at a speed of 50 feet per second. Sounds like just another day on the school playground, and not surprisingly, the door sustained no damage. With this lightweight, flexible door now hurricane-rated and State of Florida listed, we sought out a more extreme test.

It was time to get nasty. We subjected the door to ASTM F 1642, which measures blast resistance protection. The door and frame were secured inside a large shock tube that simulates the pressure wave of an actual explosion. When subjected to a force of over 18,000 pounds in mere miliseconds, the door was slightly damaged but remained operational. As the photo shows, the flexible door leaf rebounded almost to its original shape, but the rigid mortice lockset clearly did not.

If a lightweight door is properly engineered for thermal performance and corrosion protection, it will also be virtually watertight. This door actually floats.

This door was tested to the ASTM F 1642 protocol for blast resistance protection. When subjected to force in the 5.5 to 6.5 psi range, the door was slightly damaged, as seen in the bend of the aluminum at the fastener, but remained operational.

To finally answer the question of how much trauma a properly engineered, lightweight and flexible door can take before it malfunctions, we devised our own torture rack. With the door frame secured within a steel I-beam fixture, we propped the door open against an obstruction at the bottom edge, and struck it with a 215-pound sandbag swinging from a chain. By pulling the sandbag back farther and farther, we were able to create incremental impacts of up to 750 lb.ft. That's roughly equivalent to a college football linebacker hitting the door at a dead run. We were finally able to cause sufficient damage so that our door failed to latch, but it required a level of force much greater than what was expected based on our tests of other doors.

All of these tests clearly demonstrate the concept of flexural strength, but what about the rest of the story—lightweight? What's an appropriate test protocol for that? On a hot August day, the answer suddenly came in a flash of brillance. To the lake! The foamed-in-place urethane core of the lightweight door very effectively fills all voids in the interior of the door leaf and seals out moisture. In fact, the core material is the same as that used to provide a degree of safety floatation in pleasure boats. As the photo shows, the door floats very well indeed.

This combination of field success, third-party and proprietary testing proves the lightweight and flexbile approach to door design, a philosophy that would seem counterintuitive without a proper understanding of how an entrance system functions. All of these tests were passed by a standard production door engineered to the specifications detailed in this article, not specially-prepared "stunt doors," to ensure that they can survive the toughest door testers of all—your kids. dh

About the Author: *Dan Depta is marketing manager for Special-Lite Inc. Founded in 1971, the company pioneered the use of fiberglass reinforced polyester (FRP) material for door skins in the early 1980s, and today is the largest volume producer of FRP doors in the U.S. He can be reached at daniel_depta@special-lite.*