Designing for abuse resistance

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THE DESIGN-LIFE OF MOST MODERN BUILDINGS IS AT LEAST FIFTY YEARS. THUS, DESIGN PROFESSIONALS MUST STRUGGLE DAILY TO CONTROL THE COSTS OF THE FINISHED BUILDING WHILE MAINTAINING THE HIGH PERFORMANCE LEVEL OF ITS CONSTRUCTION SYSTEMS. TO MEET BUDGETS, THEY OFTEN HAVE TO MAKE TRADE-OFFS, PASSING OVER A PREFERRED HIGH-PERFORMANCE SYSTEM IN FAVOR OF A LOWER-COST SOLUTION.

Commercial and institutional owners and facility managers track both the delivered costs of their facilities and on-going repair and maintenance costs. In some cases, they have discovered that repair and maintenance costs have surpassed the original costs of more expensive systems they had eliminated for cost savings reasons.

Of special concern is the way construction professionals deal with abuse resistance with respect to the construction systems specified. Trade-offs made to save money often become expensive when viewed from a life-cycle-cost point of view.

An example is Hillenbrand Residence Hall at Purdue University. Facilities managers noted that dormitories constructed in the 1940s and 1950s with metal lath and three-coat wood-fiber gypsum plaster are far more serviceable today than dorms built with drywall in the 1970s. Although plaster has a greater installed cost, the repair and maintenance costs for drywall assemblies in high-abuse areas made them more costly over time. The designers' solution was to approach U.S. Gypsum to update its 1950s plaster specifications so they could install a new three-coat metal lath and plaster system in their new dormitory.

Cases such as this prompted U.S. Gypsum to look for alternative designs that had incremental increases in cost commensurate with incremental improvements in performance. The old adage that you get what you pay for still rings true.

Defining abuse resistance

Abuse resistance is a relative term. While esthetics is in the eye of the beholder, performance characteristics, such as sound attenuation and fire resistance ratings, have well established and understood standards by which to measure and compare systems. Although manufacturers call products "abuse resistant," there has never been an accepted industry-wide definition for abuse resistance, or test methods by which to evaluate it.

Architects and engineers from the USG Research Center surveyed the company's clients to get their perceptions about what constitutes an abuse-resistant partition. The general perception was that masonry walls are more abuse resistant than drywall assemblies. Traditional three-coat plaster walls were considered abuse resistant, while veneer plaster assemblies were considered less so. Typical building specifications reflect these perceptions. High-abuse areas, such as school corridors, are often specified masonry or three-coat plaster rather than the drywall specified in the balance of the structure, even though there are no data comparing the various systems.

Starting with perceptions of what constitutes "high," "medium" and "low" abuse resistance, U.S. Gypsum investigated the types and intensities of abuse that actual in-place construction assemblies are subjected to during their design lives, and why they fail. What constitutes a strong or abuse-resistant wall in one application, such as a school corridor, may be too weak in another environment, such as a hospital psychiatric ward. The strength of a particular assembly is also dependent on the different types of abuse it is subjected to. True abuse resistance is the ability to resist damage by all of the different types of abuse.

The three components of abuse resistance

Regardless of the application, three distinct components of abuse became clear. They include an assembly's ability to resist surface abrasion and indentations, ability to resist penetrations or punctures and ability to resist security breaches. Fig. 1 on page 12 illustrates these three abuse-resistance conditions, also defined below.

- Surface damage, such as abrasion of the partition face from high traffic under normal use, and indentation of the partition face from incidental impacting under normal use.
- Penetration through the facing materials into the stud cavity from a blunt object (such as a kick or hammer blow) or from a sharp object (such as a knife or screwdriver).
- Security penetration through the entire assembly by forced entry or ballistics.

Testing abuse resistance

U.S. Gypsum identified or developed tests to simulate each of these "real-world"

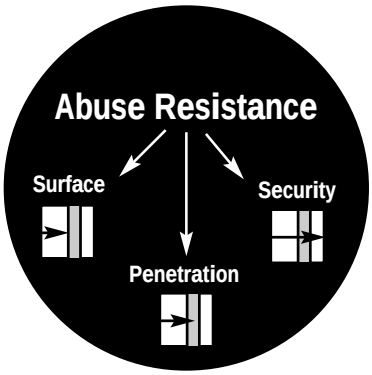

Fig. 1. Assemblies may be expected to resist three different types of abuse: Surface abrasion and indentation, penetration or puncture, and security breaches.

Fig. 2. Abrasion damage is measured using testing apparatus with weighted steel brush.

Fig. 3. Impact damage is measured using testing apparatus to approximate sledge hammer impact.

abuses. The methods could then be used to evaluate the performance of several "benchmark" assemblies which comprise the perceived low, medium and high ranges of abuse resistance. This would lead to meaningful and measurable data to confirm or refute general perceptions.

While these test methods are not yet standard in the industry, U.S. Gypsum is working closely with an independent laboratory, noted for security testing, to establish test standards based on these methods.

Abrasion testing and results

To assess the level of surface abrasion for various drywall and plaster products, U. S. Gypsum developed a modified granual embedment test. It measured each assembly's resistance to abrasion and wearing caused by high traffic in areas such as corridors and stairways. Abrasion-resistant performance is a function of the surfacing material rather than the assembly as a whole. In the test, a heavily weighted wire bristle brush is cycled over a product sample (see Fig. 2) until a measurable level of damage is observed.

For unpainted paper-faced drywall, failure under this test method occurs after about 10 cycles. Paperless gypsum fiberboard does slightly better, failing after about 15 cycles. A lime-based veneer plaster, such as DIAMOND Veneer Plaster, fails after 30 cycles. A high-strength, gypsum/sand-based veneer plaster, such as IMPERIAL Finish Plaster, did not fail even after a full 1000 cycles. See Fig. 4 for performance of more products and systems.

Application of a gypsum plaster finish was the only method evaluated which affected surface abrasion resistance. Stronger gypsum cores showed no significant improvement.

Partitions which can incorporate abrasion-resistant IMPERIAL Finish Plaster include a one or two-coat veneer plaster over gypsum plaster base or a high-strength sanded STRUCTO-BASE Gypsum Plaster over metal lath. U.S. Gypsum veneer plaster systems include a full range of fire and sound-rated assemblies.

Addition of veneer plaster in drywall designs may increase the installed cost of partitions, depending on the region of the country and the availability of trades people. However, many facilities managers realize long-term cost savings in high-traffic areas from having lower maintenance and repair costs over the life of the building.

Indentation testing and results

Indentation is caused by incidental impact of the wall during movement of people or equipment, such as impact from mail or tray carts, or from the moving of furniture. The apparatus used to simulate this damage was the Universal Impact Tester from Paul N. Gardner Company, Inc. The test impacts a sample at a fixed energy level with a rounded indenter punch.

The relative performance of tested assemblies was judged by the depth of indentation caused by an impact at 72 in.-lbs. of energy. Greater thickness, core hardness, surface hardness and back paper strength reduced indentation depths. In single-layer systems, the denser the core, the less indentation occurred. In thin samples, the board bulged on the opposing side from the impact, breaking the back paper in some cases. The thicker test samples and those with reinforced back paper maintained back paper integrity, restricting indentation.

The new SHEETROCK brand Abuse Resistant (AR) Panel (not yet available in all markets), which has a reinforced core, far exceeded conventional drywall in performance (see Fig. 5). Paperless gypsum fiber boards performed comparably to the SHEETROCK AR Panels. Performance improved with the addition of veneer plaster, especially when it was used on SHEETROCK brand AR Gypsum Base. Multiple layers of wallboard experienced less indentation than single-layer systems.

Penetration testing and results

Blunt and sharp force impact testing was conducted with the Swinging Ram Impact Penetration apparatus developed at the USG Research Center. This test procedure was developed because the soft body impact procedure of ASTM E695 does not cover a wide enough variety of abuse conditions. In the USG method, a ram is sus-

pended by cables from a steel cage frame, and sledge hammer and chisel impact heads are attached to the ram (see Fig. 3). The ram swings from its suspension cables to impact the test assembly with a known impact energy, measured in ft.-lbs.

This test measures impact energy at failure, which is the energy needed to cause through-penetration of the assembly surface into the wall cavity. Impact energies were from a single blow.

For sledge hammer (blunt object) impacts, failure occurred when the surface was fully penetrated through to the stud cavity, leaving no backing to receive joint compound/paper tape repair. There were three types of failure: Clean penetration when impact caused a clean, circular hole in the partition surface; crushed penetration when increased energy levels caused deeper indentations, greater core crushing and incremental reinforcement tearing; or practical failure. “Practical failure” occurred when the back-reinforcing materials (i.e., paper or mesh) were not punctured, but indentation was so deep into the wall cavity that repair with joint compound would be impractical.

Blunt object penetration resistance is a function of panel flexural strength, density and surface hardness, and is affected by the core composition and the type and placement of reinforcement. For example, a higher density core that resists indentation well might be too brittle to perform well under sledge hammer impact. Hence brittle core panels, such as gypsum and portland cement, are typically reinforced with paper or glass. Paper sheets placed on the face and back of traditional gypsum panels to provide flexural strength also resist sledge hammer impact penetration. Glass fiber scrims substituted for paper on specialty panels and the addition of chopped paper or glass fiber to cores also improve penetration resistance.

Although traditional gypsum panels easily experience surface damage, their

Table 1. List of partition assemblies shown in Figs. 4, 5 & 6.

- **A** 1/2” SHEETROCK brand Gypsum Panels
- **B** 5/8” SHEETROCK brand Gypsum Panels, FIRECODE Core
- **C** 1/2” IMPERIAL Plaster Base with 2-coat DIAMOND Veneer Plaster
- **D** 5/8” IMPERIAL Plaster Base, FIRECODE Core, with 2-coat IMPERIAL Finish Plaster
- **E** Competitive 1/2” paperless gypsum fiber board
- **F** 1/2” SHEETROCK brand Abuse Resistant (AR) Gypsum Panels
- **G** 5/8” SHEETROCK brand AR Gypsum Panels, FIRECODE Core
- **H** 5/8” SHEETROCK brand AR Gypsum Base, with 1-coat DIAMOND Interior Finish
- **I** 5/8” SHEETROCK brand AR Gypsum Base, with 2-coat IMPERIAL Finish Plaster
- **J** 2 Layers - 5/8” SHEETROCK brand Gypsum Panels, FIRECODE Core
- **K** 1/2” DUROCK Cement Board with 2-coat IMPERIAL Finish Plaster
- **L** 2 Layers - 5/8” IMPERIAL Plaster Base with 2-coat IMPERIAL Finish Plaster
- **M** 3.4 DIAMOND Lath, STRUCTO-BASE Gypsum Plaster and 1/16” IMPERIAL Finish Plaster
- **N** 3/4” SHEETROCK brand AR Gypsum Panels with mesh reinforcement

Abrasion Resistance

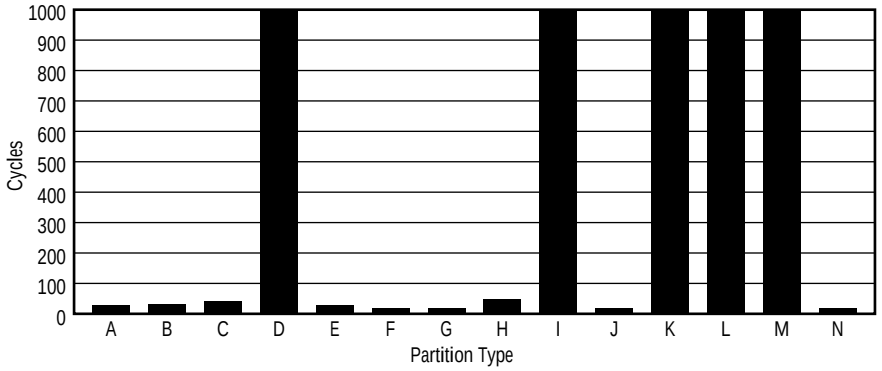

Fig. 4. Tests for abrasion resistance show that assemblies finished with IMPERIAL Finish Plaster perform better than any other gypsum assembly.

Indentation Resistance

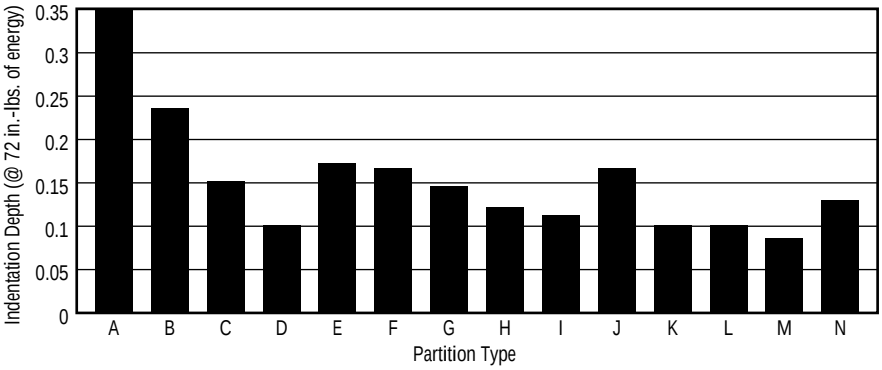

Fig. 5. In tests for indentation resistance, the less indentation, the better the performance. As in the abrasion resistance tests, the assemblies finished with IMPERIAL Finish Plaster performed the best.

Penetration Resistance

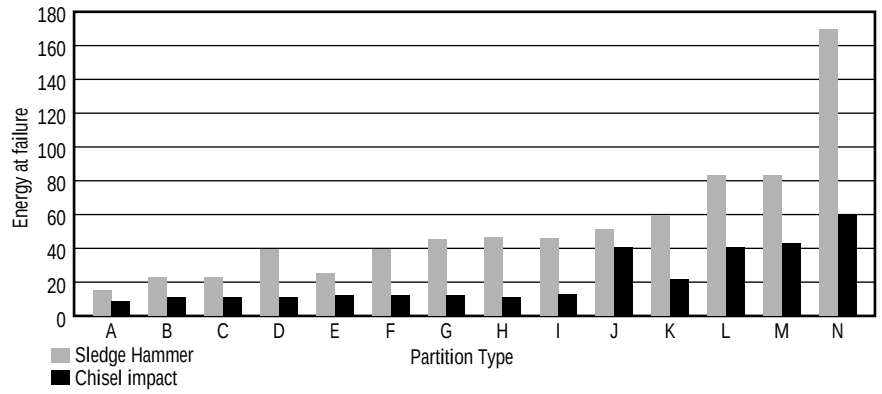

Fig. 6. In tests for penetration resistance, SHEETROCK brand Abuse-Resistant (AR) Gypsum Panels with mesh reinforcement performed the best in both sledge hammer and chisel impact.

back paper acts effectively in resisting through-penetration. Panels reinforced with heavier paper or a laminated glass fiber mesh on the back had even greater penetration resistance. Competitive gypsum fiber panels experienced less indentation than regular-core drywall products, but failed under blunt-object penetration testing at the same energy level as standard Type X gypsum panels. Reinforced systems, such as DUROCK Cement Board, with strong glass fiber mesh on both front and back, or 3/4-in. SHEETROCK brand AR Panels, with laminated glass-fiber reinforcing mesh, offer superior blunt-object penetration resistance and perform even better with a veneer plaster finish to improve surface abrasion and indentation.

Combined with reinforcing materials, increased core density and thickness also improved blunt object penetration resistance. SHEETROCK brand FIRECODE (Type X) Gypsum Panels, with their chopped glass fiber-reinforced core, outperformed regular gypsum cores of the same thickness (see Fig. 6). SHEETROCK brand AR Panels, with a specially reinforced core, outperformed the standard FIRECODE Panels. Thicker panels of similar core composition are more damage resistant due to increased effective moment of inertia. Hence, 3/4-in. SHEETROCK brand Panels, ULTRACODE Core, are inherently penetration resistant. Using multiple layers of gypsum panels (preferably laminated) is also an effective way to improve penetration resistance.

The addition of veneer plaster almost doubles the penetration resistance of regular drywall. However, the improvement for veneer addition over stronger base-panels is less pronounced. Three-coat gypsum plaster on metal lath assemblies failed similarly to gypsum panels, although at far greater loads. The metal lath performed extremely well as a back reinforcement in preventing penetration. This, combined with the high surface strength of the dense plaster, produced a very strong all-around system.

For chisel head (sharp object force) impacts, penetration was measured as the energy required to puncture completely through to the stud cavity. Sharp object penetration resistance is a function of thickness, density and flexural strength. The systems which performed best (Fig. 6) were three-coat gypsum plaster or multiple layers of wallboard with veneer plaster. Due to the concentrated load, paper or glass mesh reinforcing was not very effective. However, the damage in most cases was so localized that it did not detract from the abuse resistance of areas directly adjacent to the penetration. Penetrations thus could easily be repaired.

Security testing and results

There are industry-accepted forced entry and ballistics tests used by the U.S. Department of State (ST-STD-01.01 and ST-STD-01.02) and other institutions, and conducted by independent laboratories, such as H. P. White, Inc. and Underwriters Laboratories, Inc. Few assemblies meet the strict requirements of the State Department. Assemblies that do, such as STRUCTOCORE Security Wall Systems, are typically only used in applications such as prisons, banks and embassies. The STRUCTOCORE System, which utilizes solid-mass, high-strength plasters and steel reinforcing, were impenetrable by any of the test methods described previously. Its level of abuse resistance is beyond the design requirements of most construction. However, it may have application where security is considered a prime objective of the assembly. See USG Systems Folder SA1119 and FORM & FUNCTION, Issue 1, 1993, for more information about security walls.

Designing For abuse resistance

By testing and developing number values for each component of abuse resistance, we can rank assemblies under each method. A matrix of abuse-resistant assemblies can then be developed to present the relative performance based on the types of abuse that they will be subjected to in the field. Similar to a sound or fire rating, an abuse-resistance rating can then be determined for any partition assembly, which can then be specified by the architect along with sound and fire.

Figures 4, 5 & 6 summarize the test results of several assemblies in graph form. Fig. 4 compares the performance of various products and systems in abrasion resistance. Fig. 5 compares indentation resistance and Fig. 6 compares penetration resistance.

The types of abuse vary greatly depending upon building use. A weaker partition type may have lower installed cost, but may cost more in the long run due to high maintenance and repair costs.

Design professionals need to understand the actual performance capabilities of assemblies in order to make informed decisions. The abuse-resistance test methods described offer repeatable, measurable and comparable results for judging the relative performances of different assemblies. In addition, learning how assemblies fail is important to understanding the incremental gains that can be obtained by system improvement (such as addition of veneer plaster or a second layer of drywall). The performance data in Figs. 4, 5 and 6 can help designers to identify the best assembly available for their application. It can also provide them with hard data with which to justify a system upgrade which is threatened to be "value engineered" out of a project. ■

For more information about abuse-resistant products and systems, write Editor, Form & Function, 125 South Franklin Street, Chicago, IL 60606-4678 and request USG Systems Folder SA1119 and FORM & FUNCTION, Issue 1, 1993, for information on STRUCTOCORE Security Wall Systems; for information on abuse-resistant plaster systems, request "United States Gypsum Company Abuse Resistant Systems," P672; and for information on SHEETROCK brand Abuse-Resistant (AR) Gypsum Panels, request WB2133.

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