What is Cast Stone?

By Matthew C. Farmer

Cast stone masonry is a form of precast concrete that attempts to replicate the texture, appearance, and workability of natural dimension stone. Cast stone has a rich and successful history of use in construction. It also possesses many unique features inherent with its fabrication and raw material selection that can greatly enhance the beauty of a project in a cost-effective manner.

As with other man-made construction materials, careful attention must be paid during the fabrication and installation processes to avoid defects and deficiencies in the finished product. Through an understanding of the standards governing the industry, careful control of raw materials, and stringent quality control testing, cast stone can be an attractive and durable alternative to natural stone. Too often, however, inferior cast stone is produced and delivered to a project site, detracting from the appearance of the structure and increasing maintenance requirements to the building owner.

What is Cast Stone?

Cast stone is defined by the Cast Stone Institute (CSI)* as, "…a highly refined architectural precast building stone manufactured to simulate natural cut stone." Properly manufactured cast stone is dense and well consolidated. CSI recommends a compressive strength in excess of 6500 psi (45 MPa) (ASTM C1194)[2] and maximum absorption rates of 6 and 10% for cold water and boiling methods, respectively (ASTM C1195)[3]. The combination of low absorption and high-compressive strength makes the material generally durable and resistant to freezing-and-thawing distress. The compressive strength of cast stone is usually far greater than is necessary for the application; however, it can serve as an indicator of good quality control and future durability. Cast stone with inferior physical properties, though perhaps adequate for the particular application, may not possess the same service life of a higher quality material whose physical properties are consistent with cast stone industry recommendations.

*The Cast Stone Institute is an organization composed primarily of cast stone fabricators and other construction professionals involved in the specification, manufacture, and use of cast stone. According to the Cast Stone Institute's *Technical Manual with Case Histories*,[1] fourth edition, "The purpose of the Cast Stone Institute is to improve the quality of cast stone and to disseminate information regarding its use."

As a material, cast stone is really a variation of precast concrete. Besides sharing common constituents, cast stone is typically mixed, formed, cured, and stored in a plant environment like precast concrete, which enables rapid, consistent, and controlled fabrication. As with other concrete products, cast stone can be reinforced to increase its ability to withstand flexural and tensile loads. Despite its many similarities, cast stone does differ from precast concrete in a few ways: the mixtures integrate finer aggregates to more closely simulate the appearance of natural stone, the method of fabrication can involve very little water, and the product is virtually always used in nonstructural applications.

Cast stone can also be subject to similar quality control concerns as precast concrete. These can include a lack of consistency in mixture design causing variations in appearance, premature cracking as a result of inadequate curing or insufficient strength gain prior to form stripping, damage as a result of impact during storage, transport or erection, and contaminants or reactive aggregates in the raw materials that can cause internal distress.

When properly fabricated, cast stone can be a durable and cost-effective substitute for natural stone, but it may not always look like natural stone. Over time, cast stone can develop characteristics such as cracks, crazing, and discoloration that make it appear less like natural stone as it ages. If quality control is poor, these defects can be more apparent and appear earlier in the service life of the material. Manufacturers should be candid with architects and owners about the potential risks associated with cast stone. In essence, it is a good substitute for natural stone, but not an equal.

History

Cast stone was developed for use in wall construction as a cost-effective alternative to natural stone, primarily as trim, ornamentation, or ornate building façade elements (refer to Fig. 1). It has also been widely used as wall cladding panels. Its cost advantage is primarily due to reduced cost of the raw materials, the ability to mass produce pieces quickly, and the ability to create complex detailing with formwork and casting as opposed to labor-intensive carving or shaping. An extensive range of colors and textures of cast stone are available through the use of varied aggregates, coloring agents, and modifications to the formwork used for casting. Many designers favor cast stone not only because of the wide range of aesthetic qualities but also because of the uniformity of appearance that can be achieved with a controlled plant fabrication process.

Cast stone was first used in the year 1138, and used extensively in England and France during the 19th century. Several proprietary systems were developed during this period that used unique combinations of natural cements, hydraulic lime, and other binders. These systems were first used in the U.S. during the middle of the 19th century; many have since been abandoned in favor of the components we commonly see today: a combination of portland cement and carefully selected aggregate.

Fabrication

Two processes are typically used to produce cast stone: the vibratory dry tamping (VDT) method and wet casting. Both have potential advantages and disadvantages.

The VDT method is unique to cast stone fabrication. To achieve the appearance of natural stone, very dry mixtures of fine aggregates, cement, and water are pounded or compressed into a form on the side that will become exposed in the finished structure. This material is referred to as the face mixture. Depending on the depth of the face mixture required and the complexity or relief of the form, the face mixture is placed in layers called lifts to ensure full compaction of the material into the form. A backup mixture, consisting of coarser aggregate, cement, and water is then poured or rammed into place over the face mixture to fill the remaining portion of the form. The material is allowed to harden and cure, and then the form is stripped and the material stored until it is needed on the project site.

Cast stone produced using the VDT method can replicate stone quite accurately and is less susceptible to surface disruption as a result of free water against the form. Quality control, however, is critical to maintain consistency of both the face and backup mixtures. Changes in thickness of the face mixture can result in variations in density and appearance of the face mixture, as well as cracks due to differential shrinkage between the drier face mixture and the wetter backup mixture. Backup mixtures are usually highly variable in content because they are not visible when the finished product is used.

Wet casting of cast stone is virtually identical to the process used for precast concrete: a form is constructed and then filled with a mixture of aggregates, cement, some additives, and water. Some wet-cast methods can involve multiple lifts of material, or variations between the face mixture and backup mixture. It is allowed to harden and cure for a period of time, and then the form is removed. The formed product is then stored until it is transported to the building site where it will be used. Its principle advantages include greater consistency in physical properties through the material's thickness and better quality control of the material. Its principle disadvantages include lower production rates due to the longer curing time required before stripping, susceptibility to plastic drying shrinkage if not properly cured, and disruption of the finished faces as a result of trapped water at the form/mixture interface.

Fig. 1: An example of cast stone used as ornament at quoins, belt course, and window surrounds on this circa 1920s building

Curing methods for either technique are also highly variable depending on the cast stone manufacturer. Some cure their product using water misting, steam, curing compounds, or damp curing. The amount of curing also varies, depending on the fabrication process and storage practices, as well as the demand for the product on the job site. If the cast stone is insufficiently cured, then it can experience excessive shrinkage, causing cracking of the surface and increased water absorption.

Common Problems

There are a number of common problems that can occur with cast stone. Whereas some of these occur in cast stone produced using both wet casting and the VDT method, the majority of problems observed in modern construction are associated with the VDT method of manufacture. Unless specifically stated otherwise, these discussions will focus on cast stone created using the VDT method.

These problems range in importance from those that may simply affect appearance or accelerate the need for routine maintenance to those that impact the structural integrity of the material and put the public at risk. Several of the more commonly observed deficiencies found with cast stone are discussed in the following.

Excessive Soiling

Excessive soiling of cast stone surfaces can result from exposure to pollution, soot, and airborne dust. It can also be a result of these materials washing down from other adjacent building surfaces onto the cast stone (refer to Fig. 2). Because cast stone is absorptive as well as somewhat rough in texture, particulates can settle into the cast stone surface, or be deposited there by water. Cast stone with higher absorption and lower surface densities can become soiled more quickly since the surface structure is more open.

Crazing

Crazing, or craze cracking, is a network of interconnected hairline cracks (refer to Fig. 3). These cracks usually extend only a few millimeters into the cast stone; however, severe crazing can merge together to form deeper cracks that can allow moisture to reach the interior and, in extreme cases, cause loss of strength or instability. At the very least, these cracks take in moisture and dirt, causing them to discolor. Despite the objectionable appearance and potential for more severe damage, crazing is considered a nonstructural concern and not cause for rejection of cast stone by CSI.†

Fig. 2: Heavily soiled cast stone at a water table due to water run-off

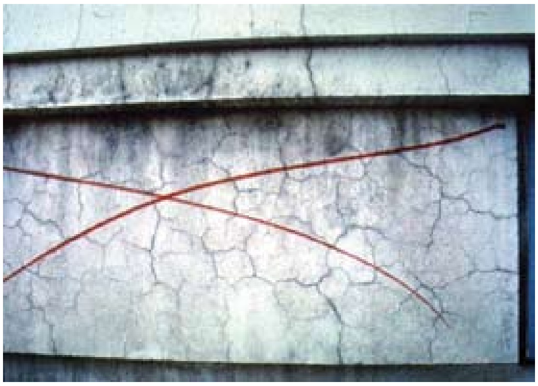

Fig. 3: Heavy crazing in a cast stone façade panel

Crazing is thought to be generally caused by shrinkage occurring at the outermost surface prior to the interior portions of the piece. It can be attributed to curing practices, variable cement content at the surface, excessive wetting and drying, or inadequate ventilation behind the cast stone. The process of tamping also contributes to crazing by creating centers of high compaction (where the tamper impacted the material) surrounded by rings of lower compaction. Crazing appears to be more concentrated in the areas of lower compaction or density. The amount of crazing is also more prevalent at locations where the face mixture is thin. The variations in thickness lead to differential drying shrinkage in the face mixture, as well as variations in density that leads to the formation of craze cracking at the surface.

Racking is probably the most common problem associated with cast stone. CSI recommends that pieces containing cracks in excess of 0.005 in. (0.127 mm) not be accepted in a quality cast stone installation.‡ Cracking can develop as a result of many different conditions and range in impact from cosmetic to a loss of structural capacity. Several of these are described in the following.

Restraint of Volume Change

Often cast stone is rigidly attached to the backup structure for support, with no allowance for volume change of the material. Although VDT-cast stone is manufactured with a low water content and experiences less shrinkage than wet-cast products, shrinkage does occur and continues for several years after fabrication. The cast stone is also subject to volume changes due to thermal cycling and will typically experience a greater temperature swing than the unexposed backup structure whose temperature range in service is often moderated by the thermally controlled building interior. If the ends of the cast stone are restrained, the differential volume change between the cast stone and the backup structure results in cracks forming across the face of the cast stone (refer to Fig. 4).

Some manufacturers will attempt to control cracking resulting from volume changes by introducing reinforcing steel in both directions across the face of the cast stone piece. Unfortunately, this is often ineffective because of the difficulty in

† CSI Technical Bulletin #32, "Crazing."

‡ CSI Bulletin #36, "Inspection and Acceptance."

Fig. 4: Crack resulting from restraint from shrinkage

Fig. 6: This crack was formed as a result of excessive loading in flexure

Fig. 5: Cracking that resulted from corrosion of reinforcing steel

Fig. 7: Poor storage and handling cast stone on site can result in improper loading and damage

achieving adequate consolidation of the material around the reinforcing steel to control and distribute the cracking. Poor consolidation around reinforcing steel in the transverse direction (perpendicular to its span) can actually form weak planes through the thickness where cracks are more likely to form.

Corrosion

Corrosion of embedded reinforcing steel can lead to cracking at the surface of the cast stone. This type of cracking is often accompanied by delamination of the material at the depth of the reinforcement, leading to further instability of the cast stone in the form of spalls (refer to Fig. 5).

Insufficient Strength

Although cast stone is typically not heavily loaded in most building applications, pieces can develop relatively high flexural stresses if they are spanning across openings, not fully bedded along their length, or in any other orientation with just two points of support. The flexural stresses are exacerbated if the piece is long and slender. Flexural cracking will typically form in the middle third of the span and run from the top to bottom edge of a horizontally oriented piece (refer to Fig. 6) or across a piece that is oriented vertically, such as a window jamb.

Handling

Cracks can also develop as a result of mishandling or unintended loading during transportation or erection. Cast stone is usually stripped shortly after forming, moved to a curing facility, moved for cleaning, and moved again to yard storage. It will often be transported to the project site prior to gaining full strength, making it more susceptible to damage while being loaded and unloaded. Cracks can develop if a piece is picked up or stored in a manner not intended (refer to Fig. 7); many cast stone fabricators will furnish lifting hardware cast in larger pieces to avoid damage during lifting operations.

Patching Failures

Patching is the process of repairing a spall or chip in cast stone by placing into the defect a fresh, formable cementitious material mixed to match the damaged cast stone as closely as possible. Patching is usually performed by the manufacturer of the cast stone, after the piece is installed.

Despite duplicating the cast stone components and their proportions, patches rarely match in all environmental conditions because the density and absorption of the original material cannot be replicated when the patch is installed. Because it is so difficult to obtain a good match between the patching material and the cast stone, only damage truly noticeable should be repaired (refer to Fig. 8). Pieces with spalls or chips greater than 8 in. (203 mm) square should be replaced. No matter the size, an acceptable patch must not be visible from more than 20 ft (6 m) away.[§]

Fig. 8: A patch relying solely on cementitious bond in an overhead condition. Note the failure of the feathered edge at left

Fig. 9: Patches that have failed and have become unstable should be removed

Patches fail by shrinking excessively or debonding from the substrate. Water can work between the patch and the cast stone substrate through separations at the bondline resulting from shrinkage; water can further degrade the patching material, become trapped and freeze, promote efflorescence, or simply make the patch more visible and detract from the overall appearance of the cast stone. Unstable patches that are debonded from the substrate or severely cracked should be removed to prevent them from falling out on their own, particularly where pedestrians or traffic could be impacted (refer to Fig. 9).

Corrosion of Reinforcing Steel

Whereas most cast stone is not used in load-bearing applications and does not require reinforcement, reinforcing steel or reinforcing bar can be used to increase its strength in flexure or enhance its ability to be handled or transported without damage. Placement of reinforcing steel is of particular concern in VDT-cast stone panels and should be avoided. Usually the face mixture is placed first, then the steel is set, and the backup mixture poured around it. Therefore, this process does not allow for the reinforcing steel to engage the face mixture. If the backup mixture is dry-tamped as well, it is nearly impossible to achieve adequate consolidation around the reinforcing steel that is sufficient to develop its strength.

If it must be used, wet-cast methods of fabrication are preferable so that the reinforcement can be fully encapsulated in cementitious material. It is also important to provide adequate cover over the steel to increase the time it takes for carbonation to reach the depth of the steel. Reinforcement that is less susceptible to corrosion, such as galvanized or epoxy-coated bars, also help to reduce the risk of corrosion-induced distress.

Spalling

Spalling and incipient spalling can occur for a multitude of reasons. Spalls can develop at anchor points where stresses are high and the cast stone is cut to receive the anchors. It can also occur as a result of setting procedures—pry bars are often used to position the stone, and the weaker edges and corners can break due to the applied pressure.

Delamination/Separation of Lifts

Cast stone manufactured using the VDT method is compacted into forms as layers called lifts. These lifts are intended to bond to each other, with the

[§] CSI Technical Bulletin #38, "Patching."

tamper forcing the layers into intimate contact. When the material is spread in the forms, however, the material being the most highly compacted is that closest to the tamper and furthest away from the layer below. This creates zones of lower compaction at the lift lines that can be more absorptive and break down more quickly if exposed to the environment; exposed lift lines can take in a substantial amount of water and erode, leaving fissures on the surface that are visually unappealing and increase the amount of water able to reach the interior of the cast stone.

Often bond at the interface between lifts is lacking. Bond can also be reduced over time if the lift interface is exposed to the environment. Without adequate bond or mechanical engagement, the outer lift (often the face mixture) can separate from the back-up mixture and become unstable (refer to Fig. 10). This condition, in combination with the presence of cracks in the face mixture, can allow portions of the face mixture to fragment and spall.

Fig. 10: Delamination of the face mixture from a large spandrel panel. Round patches are patches from prior core sampling

Solutions

Over the years, many creative approaches have been developed to restore, repair, and maintain cast stone. The cast stone industry and professionals engaged to correct deficiencies in building materials have developed repair materials and methods to address many of the problems previously mentioned. Some of the more common repair/maintenance approaches are discussed in the following.

Cleaning

Most soiling can be treated successfully with conventional water rinses, detergents, or chemical cleaners. The use of more aggressive cleaners, such as those containing acids, should be avoided or used judiciously since they can dissolve the cementitious binders in the material and lead to erosion and roughness. Cleaning with high-pressure water (greater than 300 psi [2 MPa]) should also be avoided as it can remove the paste surrounding the aggregate, roughening the surface. If the surface of the cast stone is rough or cracks are present, more debris is retained, making the material "dirtier" in appearance. Cracks are more difficult to clean because the soiling material is drawn more deeply into the crack where conventional surface cleaning may not reach.

Water Repellent Application

The application of penetrating water repellents such as silane and siloxane blends to cast stone can reduce its absorption and improve its resistance to soiling by making the surface hydrophobic and less able to absorb contaminants deposited by water. Low water absorption is critical to maintain durability, reduce the appearance of crazing, and reduce soiling overall.

If cast stone is exhibiting visible crazing, water repellents can be applied after cleaning to help prevent the crazing from becoming more pronounced. It prevents contaminants from being redeposited in the cracks and also prevents water from wicking into the body of the cast stone.

Re-etching

When originally fabricated, a cleaning solution most often containing muriatic acid is used to remove the excess paste at the surface and to expose the brighter stone aggregate. Occasionally, if soiling is severe, or if crazing is visible and darkened by contaminants filling the surface of the fine cracks, a similar acid-based wash can be used to improve the appearance. The stronger cleaning solution aggressively attacks the material in the cracks and surface irregularities. The author's experience suggests that the appearance of shallow crazing can be improved with this method and is worth attempting; however, older crazing that penetrates more deeply into the surface is not typically improved by the application.

One must also consider, however, that it is far more difficult to apply an acid wash to cast stone once it is in place, particularly if it is oriented in a vertical position. Adjacent surfaces often must be protected from damage by the caustic cleaners, and run-off must be collected and neutralized or otherwise controlled.

Architectural Coating

When the cast stone is severely crazed, soiled, discolored, or contains a number of poorly matched patches, an architectural coating or pigmented sealer can be an attractive option. Although the original appearance simulating natural stone is lost, coating and pigmented sealers offer a consistent, fresh appearance (refer to Fig. 11). Coatings will bridge small cracks and surface irregularities, and provide a water-resistant finish for the cast stone, reducing future concerns about absorption.

Coatings can range in formulation from acrylic elastomeric to potassium silicate-based materials. The most critical characteristic is breathability, or its ability to allow water vapor to pass from the cast stone to the exterior. Coatings that are not sufficiently breathable will trap moisture, peel, blister, and encourage freezing-and-thawing deterioration within the cast stone. Coatings and sealers do require reapplication; our experience suggests recoating should be anticipated every 5 to 10 years, depending on the product and its environmental exposure. Most coatings can be easily cleaned with mild detergents.

Crack Treatments

Cracks that are nonstructural but can allow excessive water penetration to reach the interior of the cast stone should be sealed. Cast stone producers will often rub a cementitious slurry or grout into the crack, filling up the surface; however, the crack quickly reforms through the thin brittle application. To more successfully seal cracks, the surface of the crack should be widened and deepened to accept an appropriate amount of material. Elastomeric sealant, cementitious grout, and structural adhesives have all been used with mixed results. The more rigid materials have a more pleasing appearance but can fail even if the crack is considered stable. Sealants are more forgiving to movement but can be more visible due to the textural differences between them and the surrounding cast stone.

Patching

As mentioned previously, patching of cast stone is inevitable. Often, the first priority for the manufacturer is to install a patch that minimizes the impact to the cast stone and matches well. Unfortunately, these patches often fail due to poor surface preparation and reliance on bond strength of the patch material to hold it in place. Because the patch will shrink after its placement in the cast stone, the bond can be broken as a result of the volume change. The manufacturer will also typically taper the patching material out to the edge of the chip or spall, producing a thin, fragile edge. These feathered edges do not have the integrity to stay bonded and break off, leaving the rest of the patch vulnerable to increased water penetration.

Proper patch installation must make compromises in the appearance. A spall must sometimes be broadened and deepened so that the patch material will be firmly engaged into the surface. The edges

Fig. 11: Example of architectural coating applied over supplemental anchors

Fig. 12: Preparation for patch repairs. Note the saw cut edges and supplemental anchors to engage the new patch material

must be cut to eliminate feather edging, and mechanical anchoring is necessary to ensure that if the patch does lose bond, it will stay engaged in the substrate (refer to Fig. 12). These practices will produce a patch that is more noticeable, but one that will be far more durable.

Industry Quality Control

The document most referenced by architectural specifications today with respect to the design, use, and manufacture of cast stone is the CSI *Technical Manual*; it has become the most widely accepted standard for the industry. Most specifications will defer to the requirements for cast stone expressed in its standard specifications. This document in turn references ASTM C1364, "Standard Specification for Architectural Cast Stone,"[4] which is maintained by ASTM Committee C-27, Precast Concrete Products, and the direct responsibility of Subcommittee C27.20, Architectural and Structural Products. The language between these two documents is quite similar, with the CSI specification inclusive of the ASTM requirements.

Although many improvements have been made recently regarding the quality of cast stone as a result of more stringent requirements for quality control in the industry, there are still some areas where the standard specification and industry requirements could be improved to better ensure a quality product will be delivered and the material's end user will be satisfied.

Cast stone is a unique material that offers modern designers the appearance of natural stone, but with all the advantages of a manufactured product. Conversely, proper manufacturing processes and quality control are critical to providing a good cast stone product. A better understanding of the material's advantages and limitations are essential to make certain that all parties involved in the cast stone application are pleased with the final installation.

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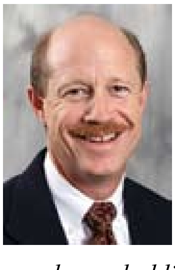

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