# COMPARING LABORATORY AND FIELD DURABILITY TESTING OF STONE

Accelerated Weathering Testing of Stone

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Durability of Building Materials and Components 8. (1999) *Edited by M.A. Lacasse and D.J. Vanier*. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, pp. 624-634.


## Abstract

Research is being performed at Wiss, Janney, Elstner Associates, Inc. (WJE) laboratories toward developing an accelerated weathering test procedure that can be used to simulate the effects of natural weathering on stone cladding. Several stone types are currently undergoing laboratory and field testing at WJE. These tests are being performed to verify that an accelerated weathering test procedure used in laboratory studies can produce comparable results to the natural weathering of the same stone types. A non-destructive test procedure is used at set intervals during the weathering periods to determine the changes in the Relative Dynamic Young's Modulus of Elasticity (sonic modulus). The laboratory test specimens are usually monitored at 0, 10, 20 30, 50, and 100 freeze-thaw cycles while the field test specimens are being monitored semi-annually. The changes in sonic modulus using the accelerated weathering test procedure are similar to the changes determined from naturally weathered specimens. In addition, the changes in the sonic modulus have been shown to correlate to changes in the flexural strength property of the stone. Based on these tests, service life estimates can be determined for various stone types when they are used as cladding on buildings. The stones under evaluation for the current natural weathering studies are limestone, marble, and granite. We have accumulated three years of data and plan to extend the test program for a total of ten years. The results of this testing can be used as a guideline in developing clear specifications that address stone durability on an accelerated weathering basis.

Keywords: durability, stone, cladding, accelerated weathering, natural weathering, building cladding, laboratory testing, field testing.

# 1 Introduction

Durability is an important issue to consider when specifying stone for exterior exposure. In the past, it was only through experience that people could evaluate the durability of specific stone types. Experience is still a valuable tool, but it is now possible to perform tests that determine the life expectancy of a particular stone type that is to be provided for a specific building facade.

Stone is subjected to a variety of weathering conditions that are both natural and unnatural. Each type of weathering condition will produce different effects on the stone durability. Weathering is a result of changes in the body of the stone. Water and atmospheric gases are the reactants that cause the weathering process.

The rate of weathering is dependent on the macro and microenvironments. The macroenvironment is the ambient atmospheric weather conditions while the microenvironment is related to weather conditions at specific locations of a building facade.

## 1.1 Forms of weathering

The influences that affect the rate of weathering are temperature, moisture, and air pollutants. The average rainfall is a major controlling factor of the weathering rate because the rainwater will carry air pollutants into the stone by absorption. The absorbed rain and industrial pollutants will accelerate the weathering rate. It is these factors and the mineralogy that results in the variability of behavior for natural stone.

### 1.1.1 Chemical weathering

Stone exposed to air pollution may show signs of weathering by undesirable discoloring, loss of polish and surface erosion (delaminations and spalling). Air pollutants, or acid pollutants, can have serious detrimental affects on carbonate stones, such as limestone and marble. Rainfall that is absorbed into the stone is a controlling factor of weathering. The amount of $CO_2$ in the water causes the rate of dissolution of the carbonate minerals. Depending on the mineral composition of the stone, the water can cause the material to dissolve by percolating water solutions or by chemical decomposition. Higher temperature increases the chemical agitation of the minerals. Hence, such reactions are greater in tropical areas than in the colder temperature zones.

### 1.1.2 Temperature weathering

Depending on the location of a building, the temperatures on the surface of a dark stone facade can become as high as 88°C (190°F) during the summer and as cold as –23°C (–10°F) during the winter. The changes in temperatures can cause decomposition of a stone facade due to differential volume changes (expansion and contraction) of the various mineral grains that comprise the stone. The differing rates of thermal expansion of individual mineral types that comprise a single stone will cause the deterioration. All minerals expand with increasing temperature, but they expand at different rates and in different directions. The volumetric or linear expansion of the different minerals can cause micro cracking. The micro cracking will lower the strength of the stone and allow other weathering phenomena to enter and accelerate the disintegration process.

1.1.3 Freeze-thaw weathering

Damage to the stone can result as entrapped water expands under freezing conditions within the pores, cracks, and fissures that comprise the structure of the stone. The absorbed water forms expansive ice crystals that produce high compressive forces on the walls of the pores, cracks, and fissures. The compressive forces will produce tensile stresses on the crystalline bonds between the mineral components of the stone. Cyclic wetting, drying, freezing and thawing can eventually lead to fatigue of the crystalline bond and cause decomposition of the stone. Because of this, the tensile strength of the bond between mineral grain particles is of greater importance than the overall compressive strength when considering the durability of a stone.

The pores may also contain clays, some of which will expand when they become wet. The swelling of these clays will also produce large compressive forces within the stone. It may not be apparent that the swelling is occurring because the expansion of the clay may be a normal characteristic for the particular stone. The tensile strength of the bond between crystals may be great enough to resist the forces of the expansive clay. However, the stone may deteriorate rapidly when it is installed on the side of a building and the clay becomes wet and freezes.

# 2 Accelerated weathering testing

## 2.1 Test considerations

An accelerated weathering test procedure that can provide accurate durability information for natural stone must take into consideration the affects of temperature, water and atmospheric pollutants. Durability is an important issue to consider when specifying a stone that is to be used for exterior cladding on a building. Over the past forty years, an accelerated weathering test procedure for stone has been in the process of development. Results from the test have shown an excellent correlation to results from natural weathering.

## 2.2 Test procedure

The developed test procedure consists of placing a stone specimen with minimum dimensions of 30 mm (1¼ in.) thick by 100 mm (4 in.) wide by 380 mm (15 in.) long in a 4 pH sulfurous acid solution. The specimen is immersed only 6 mm (1/4 in.) to 10 mm (3/8 in.) deep in the solution in addition to being set on 6 mm (1/4 in.) diameter rollers in a stainless steel pan. The rollers assure that the entire stone face is subjected to the solution. The solution simulates acid rain on the exposed exterior face of a stone panel.

The specimen is then subjected to 100 cycles between a temperature range of -23°C and +77°C (-10°F and +170°F). A fresh solution is used after each 25-cycle interval. It is common to achieve four freeze-thaw cycles for each day of the testing.

Prior to the weathering test, the specimen is evaluated for determination of the Relative Dynamic Young's Modulus of Elasticity (sonic modulus) using procedures as outlined in ASTM C215, "Test Method for Fundamental Transverse, Longitudinal and Torsional Frequencies of Concrete Specimens." Sonic modulus testing is a non-destructive means to evaluate the changes in the stone properties during the accelerated weathering test procedure. The test procedure entails spanning a specimen between two points and then tapping the specimen to produce vibration. A test device – the Rockland 5804A Analyzer as manufactured by Rockland Scientific Corporation – is used by WJE to monitor and record the frequency of the vibration. This test device is not the same as that noted in ASTM C215, but it provides identical test results. Depending on the durability of the stone tested, a change in frequency may be determined. The frequency and weight of the specimen are used as known variables in an equation to determine the sonic modulus. This provides an indication of the relative stiffness of the stone.

The sonic modulus testing is performed at a minimum of 25-cycle intervals. However, the most significant changes in sonic modulus are normally apparent during the first 50 freeze-thaw cycles of the testing. Therefore, it is usually beneficial to perform the testing at more frequent intervals during the first 50 cycles.

Unweathered companion specimens are tested for determination of flexural strength using procedures as outlined in ASTM C880, “Standard Test Method for Flexural Strength of Dimension Stone.” In order to verify the changes in mechanical properties, flexural strength tests are also performed on the accelerated weathered specimens after the weathering.

## 3 Correlation studies between accelerated and natural weathering

Tests have been performed to confirm a correlation between data obtained from accelerated and naturally weathered stone. Results of these studies are provided in Sections 3.1.2 and 3.1.3. The studies were performed by subjecting similar stone types – both weathered and unweathered – to sonic modulus and flexural strength testing. The authors are not aware of others having performed such studies.

In several cases, stone specimens were obtained from attic-stock panels that had been stored within a building and, therefore, never subjected to natural weathering. Stone specimens were cut from the attic-stock panels and the exterior facade panels for the comparison studies. Charts were plotted using sonic modulus and/or flexural strength test data from both the weathered and unweathered stone. The charts were analyzed to determine the location of the tangent between the curve for the weathered stone to the curve for the unweathered stone that was subjected to the accelerated weathering test. The tangent provided an indication of the equivalent number of years of natural weathering to the number of freeze-thaw cycles of the accelerated weathering test procedure.

## 3.1 Marble studies

The accelerated weathering test procedure has been performed on many different types and groups of stone specimens for past projects. The following comprises a few examples of testing projects using marble that established a correlation between natural and accelerated weathering of stone.

### 3.1.1 Rooftop studies in Chicago, Illinois

About forty years ago, twelve domestic marbles were placed on the roof of a building in Chicago, Illinois. Sonic modulus testing was performed quarterly on the marble specimens over an eight-year period. The results of this testing are provided in Fig. 1. As can be seen, most of the marbles exhibited a leveling of the curves after 1½ years of natural weathering. Similar leveling of the sonic modulus curves has typically been evident after 50 freeze-thaw cycles of the accelerated weathering tests.

One of the stones used in the rooftop studies was Danby marble from Vermont. Recently, we had an opportunity to perform accelerated weathering tests using Danby marble. The accelerated weathering was performed for 100 freeze-thaw cycles. Figure 2 compares the results of the sonic modulus testing for the recently tested specimens with the previously studied rooftop specimens. A close correlation between the data is evident.

Based on the results of the Danby marble specimens, it was determined that approximately 100 freeze-thaw cycles of the accelerated weathering test procedure is equal to between 6 and 8 years of natural weathering in Chicago. Therefore, 12 to 16 freeze-thaw cycles can be considered equivalent to one year of natural weathering of a marble facade in a northern temperate environment.

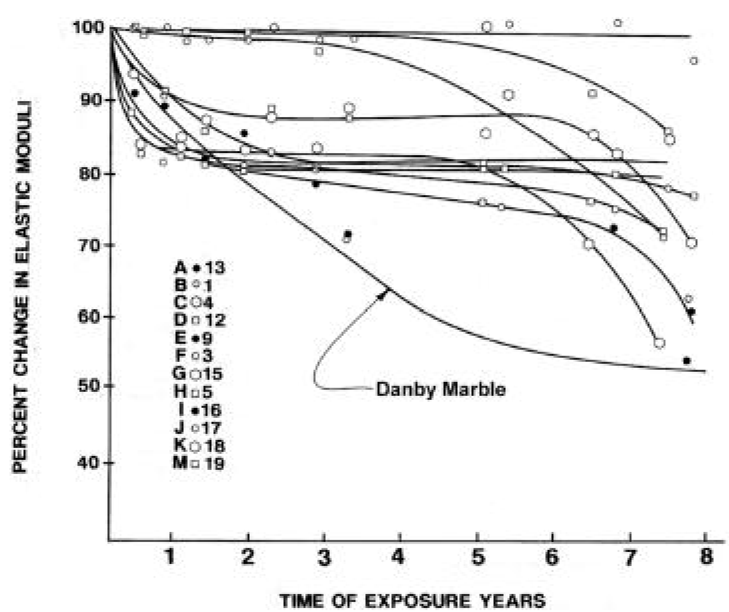


**Fig. 1: Sonic moduli determined from rooftop natural weathering studies of twelve different marbles in Chicago, Illinois**

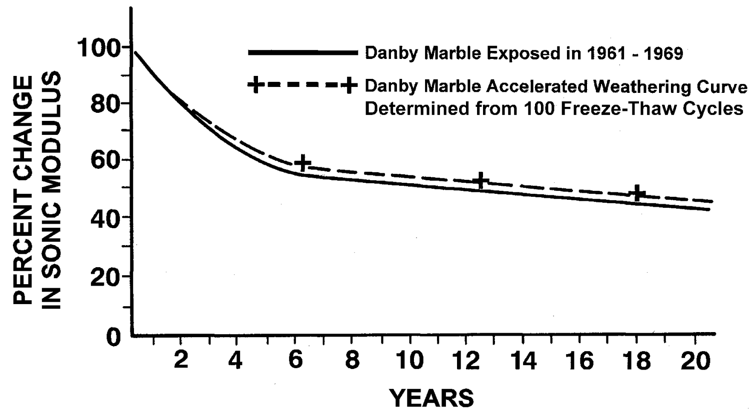


**Fig. 2: Comparison of sonic modulus test results between the previous natural weathering studies and the recent accelerated weathering test**

3.1.2 Marble-clad building in Chicago, Illinois

Studies were performed using flexural strength testing. Specimens were cut from panels of a building in Chicago that had been exposed to natural weathering for approximately 15 years. In addition, specimens were also cut from panels that had been stored indoors as attic-stock. The specimens were subjected to flexural strength testing at 0, 100, 200 and 300 freeze-thaw cycles of the accelerated weathering. The result of the testing for both groups of specimens is presented in Fig. 3. It can be seen that the charted curve for flexural strength is very similar to the charted curves from sonic modulus test data. This testing program further confirmed that about 15 freeze-thaw cycles of the accelerated weathering test equaled approximately one year of natural weathering for a marble facade in a northern temperate environment.

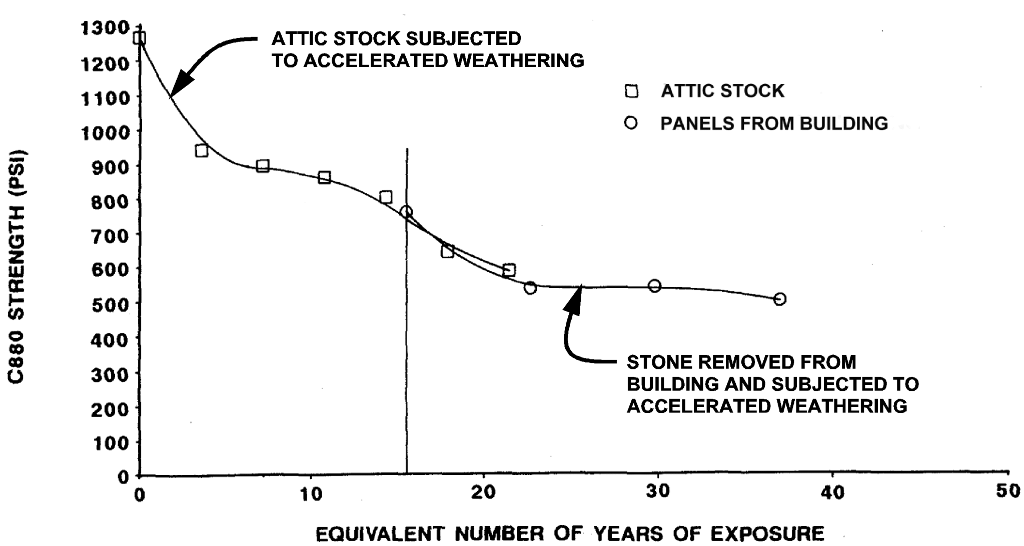


**Fig. 3: Flexural strength versus years of natural weathering determined from marble clad building in Chicago, Illinois**

3.1.3 Marble-clad building in Rochester, New York

Correlation studies were performed using natural weathered and unweathered marble from a 10-year old high-rise office building in Rochester, New York. Many panels from the building facade and panels that had been retained as attic-stock were provided for the accelerated weathering test. The results of the testing are summarized in Fig. 4. The chart shows a correlation between the sonic modulus and the flexural strength.

A weathering chart was plotted using the sonic modulus and flexural strength test data. The tangent between the sonic modulus test results of the weathered and unweathered data occurred at approximately 160 freeze-thaw cycles. Using these relationships, it was concluded that 160 freeze-thaw cycles of the accelerated weathering test procedure was equivalent to ten years of natural weathering on the building. Thus, 16 cycles were determined to be equivalent to one year of service life in upper New York State.

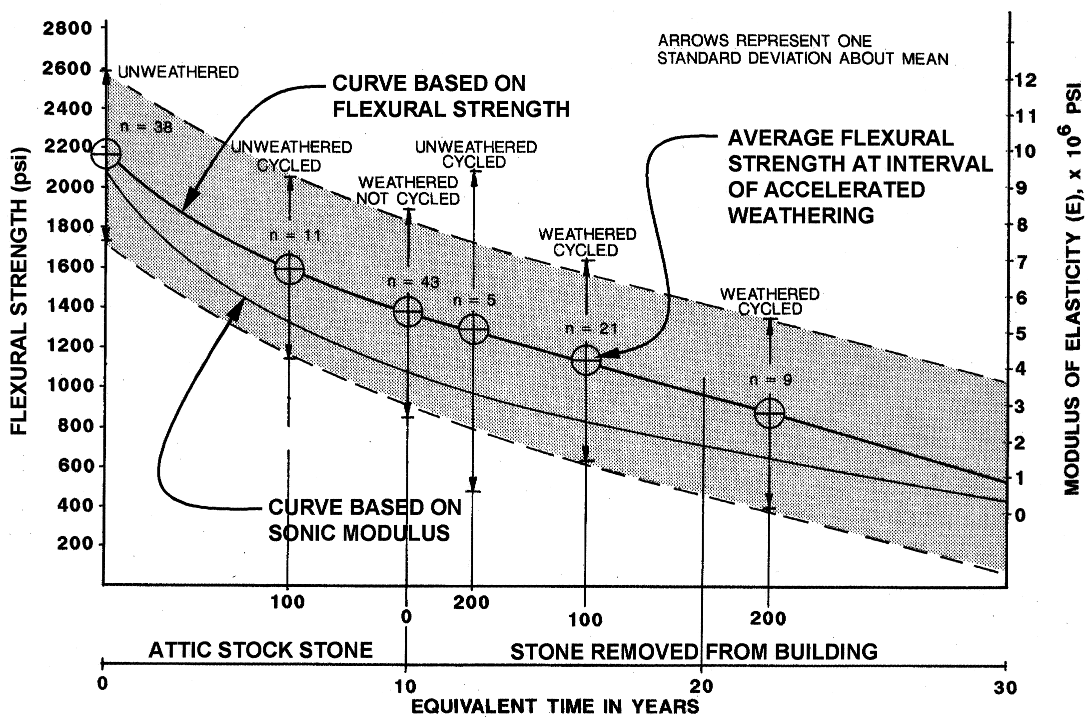


**Fig. 4: Relation of number of accelerated weathering cycles to years of natural weathering for marble clad building in Rochester, New York**

### 3.2 Granite and Limestone Studies

Similar data has also been obtained from granite and limestone specimens using weathered and unweathered stone. Changes in properties were plotted for 300 freeze-thaw cycles for granite, 500 freeze-thaw cycles for marble, and 200 freeze-thaw cycles for limestone. Based on the data, approximately 13 freeze-thaw cycles was determined to represent one year of natural weathering for granite, 12½ freeze-thaw cycles represented one year for marble and 12 freeze-thaw cycles represented one year for limestone.

## 4 Current natural weathering studies

Over the past three years, WJE has been exposing granite, marble and limestone to natural weathering on the roof of a building in Northbrook, Illinois. The stone used for the testing had never been exposed to weathering. Five specimens are used for each stone type to provide a good statistical population for the studies. The specimens face south with a slight angle. Testing for sonic modulus was performed prior to the start of the natural weathering, as well as at six-month intervals. Testing and observations of these specimens is to continue for ten years.

Figures 5 through 7 are charts that show the current status of the sonic modulus test results after three years of natural weathering. Table 1 provides a summary of the approximate reductions in sonic modulus that have been obtained.

The natural weathering curves of the current rooftop studies can be compared with the previously shown charts that were prepared from the accelerated weathering test results. A similarity is discernable between the curves.

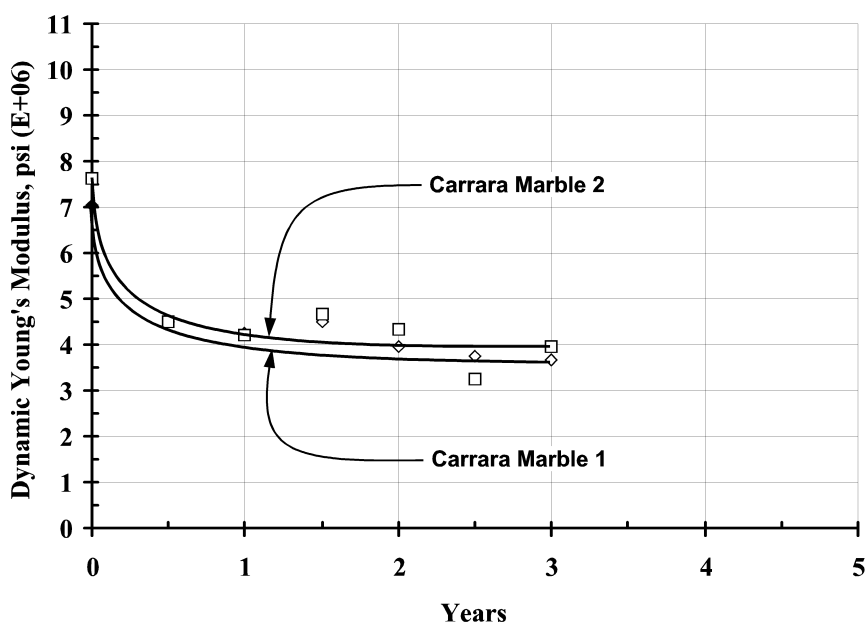


**Fig. 5: Sonic modulus curves established for the marble specimens**

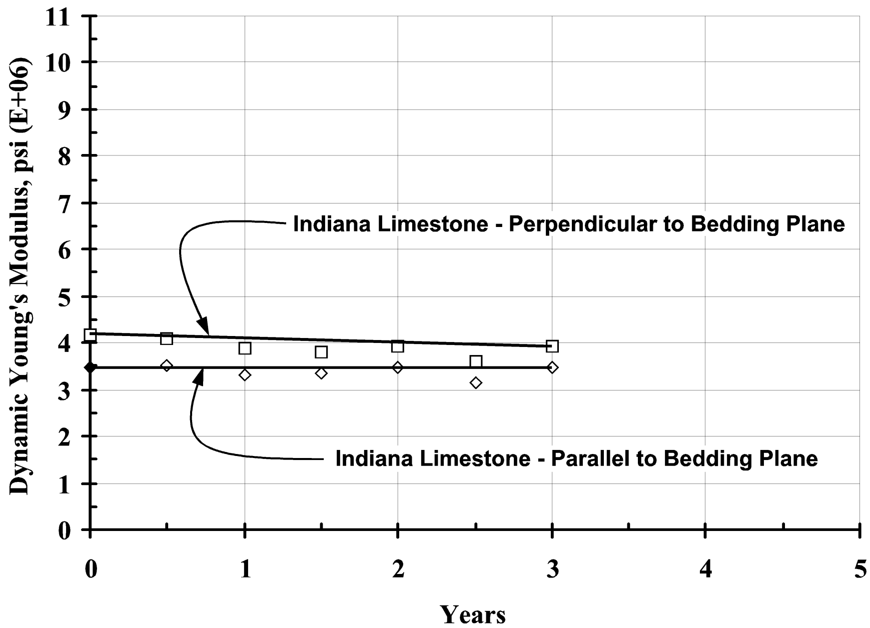


**Fig. 6: Sonic modulus curves established from the limestone specimens**

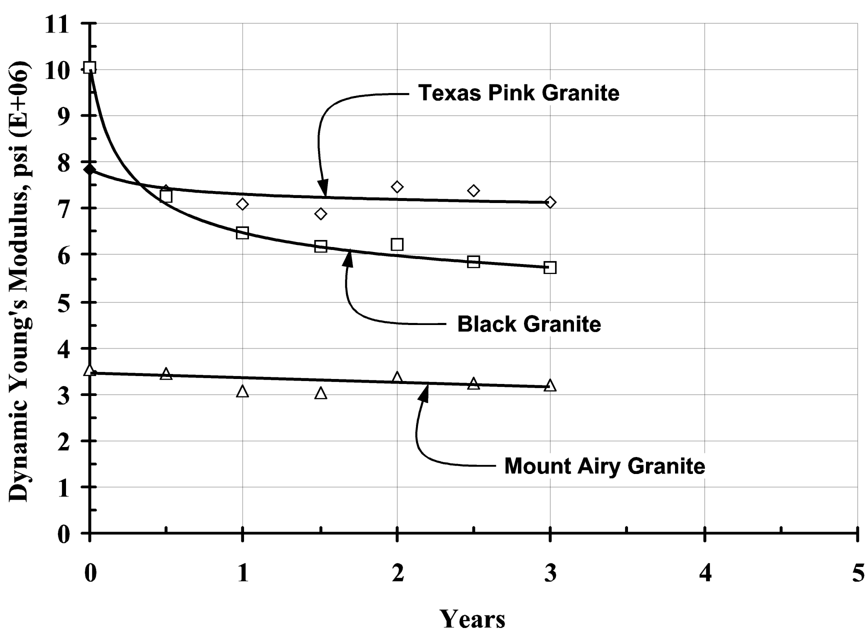


**Fig. 7: Sonic modulus curves obtained from the granite specimens**

**Table 1: Loss of sonic modulus after three years of natural weathering**

| Stone Type | Approximate Loss (%) |
|---|---|
| Carrara Marble 1 | 47.9 |
| Carrara Marble 2 | 48.2 |
| Indiana Limestone – Parallel to Bedding Plane | 0.0 |
| Indiana Limestone – Perpendicular to Bedding Plane | 6.5 |
| Texas Pink Granite | 8.7 |
| Black Granite | 43.1 |
| Mount Airy Granite | 9.6 |

The most significant losses in sonic modulus are apparent with the Carrara marble. In our past testing, we have often determined such loss in sonic modulus and flexural strength for various marble types.

The Black granite specimens are also showing a significant loss in sonic modulus. Most types of granite we have tested have performed well throughout the accelerated weathering test procedure, as is evident from the lower losses for the Texas Pink and Mount Airy granites. However, certain types of granite will exhibit larger losses in sonic modulus if they are composed of minerals that have weak crystalline bonds.

The slight loss in sonic modulus determined for the Indiana limestone specimens is common for this stone type. However, we have experienced instances where Indiana limestone has decomposed rapidly during the accelerated weathering test procedure. It was determined the deterioration of these specimens had resulted from clay inclusions in bedding planes of the stone.

Visual deterioration of the specimens is also recorded at each six-month interval. Besides the normal erosion that can be expected on the surfaces of the carbonate stone, only one Texas Pink granite specimen has shown deterioration with spalling at a corner.

## 5 Conclusions

Several years of comparison studies using accelerated and natural weathering has shown a good correlation between the test data. We have shown that the accelerated weathering test method can be used to evaluate a particular stone for durability. If naturally weathered and unweathered stone is available, sonic modulus test data can be used to determine a relationship between the number of freeze-thaw cycles of the accelerated weathering test and the number of years of natural weathering. Based on the studies performed so far, it can be assumed that between 12 to 16 cycles of the accelerated weathering test procedure is equivalent to one year of natural weathering of a stone facade in a northern temperate environment.

This information can be further used in determining more accurate safety factors for a stone facade rather than the empirical safety factors that are recommended by the stone industry. Our experience has shown that in certain situations a lower safety factor may be acceptable that can provide a more economical stone thickness or anchor spacing. This can reduce the overall cost of a stone facade.

A designer must consider a particular stone can vary from quarry to quarry, from different locations within a single quarry, and possibly within a single block of the quarry. Therefore, it is important to test the specific supply of stone for a large building project. Stone used successfully on a similar building project in the past may not have the same physical or mechanical properties for the current building project.

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