

**CRAFT**  
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MARBLE CLADDING PANELS

**PROJECT COORDINATOR:** 'E. TSCHEGG

**PROPOSERS:**

FRANZ BAMBERGER GmbH

LAUSTER NATURSTEINWERKE GmbH

CREMAR SPA

CREMARIVOLI SRL

POSCHACHER NATURSTEINWERKE AG ,

ORESTE BASTRERI KG

KARL KILIAN GmbH

**RTD PERFORMERS:**

LABOR F. MATERIALWISSENSCH., TU

INSTITUT FÜR GEOLOGIE, TU

ABTLG. RÖNTGENPHYSIK, TU

INST.F.MET.U.PHYSIK, BOKU WIEN

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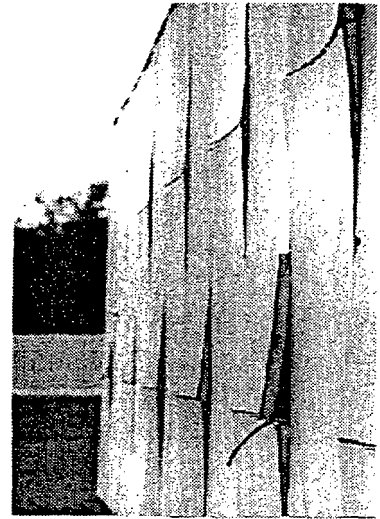
## 2 Summary

### 2.1 Keywords

natural stone, marble cladding, anisotropy, material properties, testing techniques.

### 2.2 Abstract of Results and Benefits of the Project

Facade panels made of crystalline calcite marble bow considerably at times several years after installation. This phenomenon is gaining increasing attention due to a growing number of cases of damage world-wide. The best-known examples are the Amoco-Tower in Chicago, the Finlandia-Hall in Helsinki (Fig. 1) and the Grande Arche de la Défense in Paris. The image of marble as a facade material, which has been excellent up to now, is suffering a lot from these cases of damage, and marble has to face increasing competition from other building materials (e.g. other natural stones, artificial marble, aluminium, glass). Within the framework of this CRAFT project, seven natural stone enterprises (SMEs) from three EU member states have therefore had research carried out in order to safeguard the quality, safety and therefore the image of marble as a facade material.



**Fig. 1: damaged marble panels, Finlandia Hall, Helsinki**

By means of the investigations carried out the deformation behaviour of different types of marble under different weathering conditions was characterised. The anisotropy (texture) and grain size of marble proved to have an effect on the behaviour of the material. Numerous methods for determining the texture were tried out. Dilatometer technology (determination of thermal expansion) in particular could be developed into a precise and cost-efficient method. Measuring ultrasonic velocity in marble was also tested as to its suitability for determining anisotropy.

On the basis of these results, a testing programme for determining the durability of dimension of marble was developed. Subsequently it was tested as to its feasibility in the participating industrial enterprises, and was then adapted according to the practical requirements. Recommendations for the production and installation of crystalline calcite marble panels were derived from these results (consideration of preferred orientation). By observing these recommendations, the durability and safety of marble facades can be increased. The new testing programme can determine the suitability of different types of marble for different areas of application by means of only few material parameters. Thus the testing programme ensures that in future marble can be safely applied also outdoors.

In order to carry on the research activities after the completion of the project and to put the results into practice, **WASP** (Working group for the Assessment of Stone Properties) has been established at the Vienna University of Technology. It offers materials testing for producers and users in the EU.

The findings and the practical know-how gained in marble testing up to now, will also be applied to other natural stones in future.

The findings represent the state-of-the-art in marble testing and should therefore be considered in negotiations on the harmonisation of European natural stone standards.

### 3 The Consortium

#### 3.1 Partner Organisations

##### 3.1.1 SMES

###### **Franz Bamberger GmbH** (prime proposer)

Wr. Neustädter Straße 137-139, A-25] 4 Traiskirchen

Tel.: +43 225280521 Fax: +43 22528535214 ‘~

###### **L a u s t e r Steinbau GmbH** ,

Albrecht Lauster, Enzstraße 40, D-70376 Stuttgart

Tel. 07115967-0 Fax 0711596750

Herbert Huster, Simmeringer Hauptstraße 12, A-1110 Vienna

Tel. +43 17483255 Fax +43 17483256

###### **Crema S.p.A. Marmie e Graniti** (Crema Rivoli S.R.L.)

M. Mazzi, Via Palazzina 1122/b, 1-37020 Volargne di Dolce (Verona)

Tel. 0039456861899 Fax 0039456862292

###### **Poschacher Natursteinwerke AG**

Heinz Berger, Sängershofgasse 47, A-2512 Tribuswinkel

Tel. +43 13108999 Fax +43 13108999-9

###### **Karl Kilian GmbH**

Rudolf Stummer, Wiener Straße 55, A-3002, Pürkersdorf

Tel. +43 22313824 Fax +43 22313151-3

(Oreste Bastreri KG)\*

(Ilse Katlein, Nikolsdorfergasse 35-41, A-1050 Vienna)

\*) taken over by Franz Bamberger GmbH on 1,8-1996.

##### 3.1.2 RTD Institutions

###### **Institute for Applied and Technical Physics, Vienna University of Technology**

Elmar Tschegg (project coordinator) and Clemens Widhalm (deputy project coordinator)

Wiedner Hauptstr. 8-10/137, A-1040 Vienna

Tel.: +43 158801 ext. 5438 or 3045 Fax: +43 15868814

###### **Institute for Geology, Vienna University of Technology**

Walter Eppensteiner, Karlsplatz 13/203, A-1040 Vienna

Tel.: +43 158801 ext. 3283 (Secret.: ext. 3077) Fax: +43 15044235

###### **Institute for Meteorology and Physics, Vienna University of Agriculture and Forestry**

Stefanie Stanzl-Tschegg, Türkenschanzstraße 18, A-1180 Vienna

Tel. +43 14705820 Fax: +43 14705820-60

### 3.2 Consortium Description

All SMES participating in this CRAFT project are natural stone enterprises. Some of them have their own quarries. All of these firms produce natural stone building and decorative components and also install them.

Prime proposer Franz Bamberger is the managing director of Franz Bamberger GmbH. He is also Master of the Austrian Stone Masons Guild.

Poschacher Natursteinwerke is a member of VÖN (Vereinigung österreichischer Natursteinwerke - Association of Austrian Natural Stone Enterprises), of which Franz Bamberger GmbH, Kilian GmbH and Lauster Steinbau GmbH are also members.

The research activities were carried out at the Institute for Geology and the Institute for Applied and Technical Physics at the Vienna University of Technology, as well as at the Institute for Meteorology and Physics at the Vienna University of Agriculture and Forestry.

Elmar Tschegg, the project coordinator, is head of the Laboratory for Material Science at the Institute for Applied and Technical Physics. This laboratory has great expertise in measurement technology, in particular in the areas of fracture mechanics, material damage analysis, dilatometric measurement and acoustic emission. Therefore a large part of the laboratory measurements were carried out at this institute. Some measurement appliances were specially developed or “adapted for the purposes of the project. Numeric simulations according to the Finite Elements method were also carried out.

Michael Mantler, head of the Department for X-ray Physics at the Institute for Applied and Technical Physics, is a specialist in the area of X-ray fine structure analyses. Therefore he was in charge of X-ray texture goniometer measurements.

Walter Eppensteiner is university professor for technical petrography at the Institute for Geology and a geological expert. He and his team have wide-ranging expertise in the area of natural stone testing for different applications” and in assessing (deterioration of natural stone installed outdoors. The institute has analysed numerous cases of damage all over Europe, and has also carried out petrographic analyses on unused material.

Stefanie Stanzl-Tschegg is university professor at the Institute for Meteorology and Physics at the Vienna University of Agriculture and Forestry and is also head of the Physics Working Group. Due to its expertise concerning climate and weather combined with physical knowledge, this institute is an ideal partner for analysing damage due to weathering. Therefore this institute took over the collection and analysis of the climatic data. Furthermore part of the fracture-mechanical investigations was carried out at this institute.

## 4 Technical Achievements

### 4.1 Project Objectives

In the last three decades more and more building facades made of marble panels have been installed, very often made of thin marble panels (3cm and less). Numerous cases of damage have shown, however, that thin marble panels can lose their durability of dimension under weathering. Typically, the panels bow first, and later on cracks occur. The marble panels can also become loose and thus can represent a considerable safety risk (see Fig. 2). Prominent examples are the completely destroyed marble facade on the Finlandia-Hall in Helsinki, the facade of the Amoco Building in Chicago, and the facade of the Grande Arche de la Défense in Paris, all made of fine-grained Carrara marble.

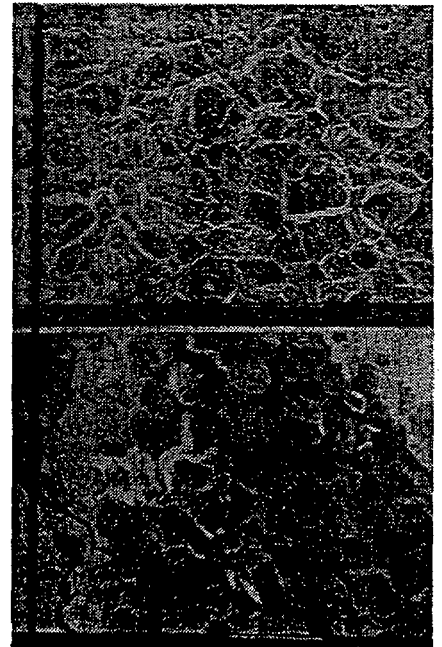


*Fig.2. Bowed panels of fine grained marble in Vienna*

The aims of the project were to establish methods for quickly determining the suitability of a particular type of marble for outdoors installation, as well as to draw up guidelines for the production, processing and installation of marble panels, thus contributing to avoiding cases of damage caused by deformations. The preferred orientation of the marble, for example, should determine the cutting direction of the panels, in order to achieve a higher degree of strength and durability of dimension. Furthermore, a new procedure for the physical pre-treatment of the panels should be developed in order to increase their durability of dimension outdoors. This procedure should then be integrated in the processing of marble products. For this purpose, those processes in the microstructure of different types of marble which lead to the deformations described were to be analysed.

### 4.2 Durability of Dimension of Marble

The liability to deformation in many types of marble is mainly due to the extreme thermal characteristics of calcite, the rock-forming mineral of calcite marble. Calcite strongly expands when being heated parallel to its crystallographic c-axis, while contracting normal to this axis. Under thermal cycling, this anisotropic behaviour leads to stresses at the grain boundaries which can lead to structure loosening. As a consequence, water absorption capacity increases. These can accelerate further damage to the material due to dissolved pollutants and salts as well as due to frost. Fig. 3 shows SEM-pictures of fracture surfaces of unused (above) and of damaged (below) fine-grained marble. With the damaged marble, the loosening of the grain boundaries can be seen clearly. As mainly one side of facade panels is exposed to weathering influence, this can possibly cause deformations as described above.

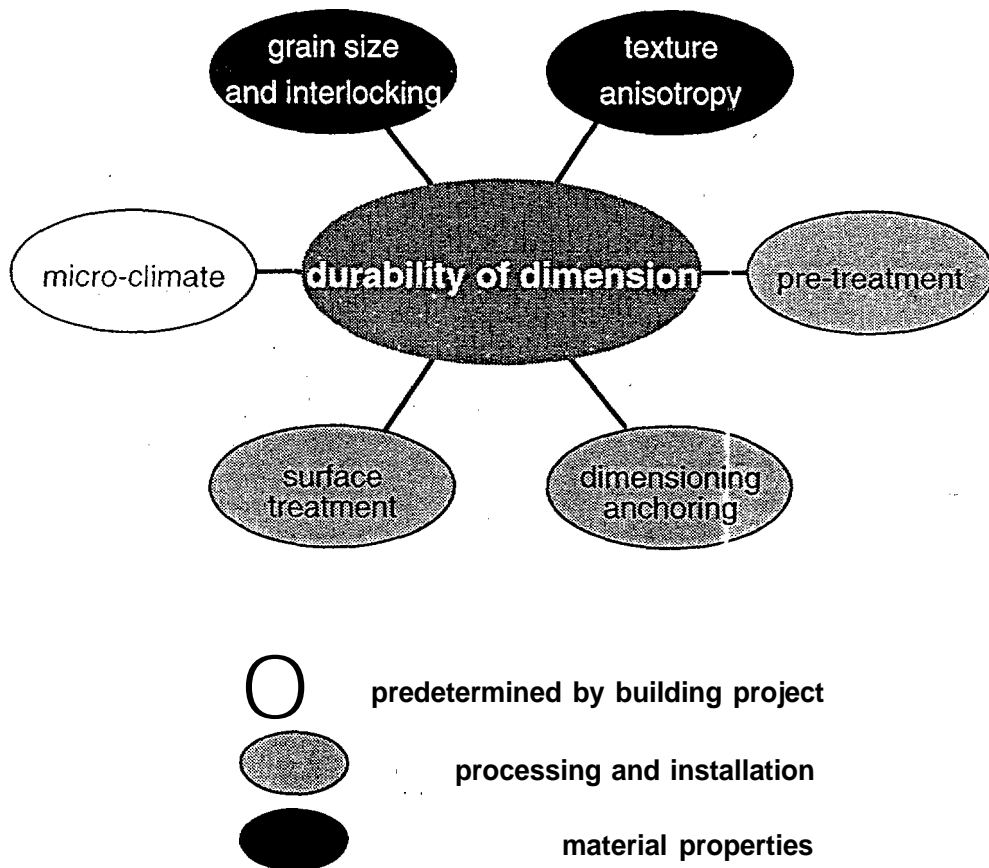


*Fig.3: Fracture surface of unused (above) and weathered (below) fine grained marble*

An extensive **analysis of cases of damage shows that a lack of durability of dimension in facade components depends on different parameters:**

- microclimate (climate, exposure to sun and rein, splashed wate: etc.)
- grain structure, medium grain size, interlocking of groins among each other
- texture, crystallographic anisotropy
- dimensioning and anchoring
- surface treatment (polished, grounded, sand blasted, bush hammered)
- pre-treatment (hydrophobic treatment, sealing, physical pre-treatment)

These parameters are partly predetermined by the' building project, or depend on the choice of a particular type of marble? or can be influenced by processing (see figure 4 below).



**Fig. 4: different parameters for durability of dimension of marble**

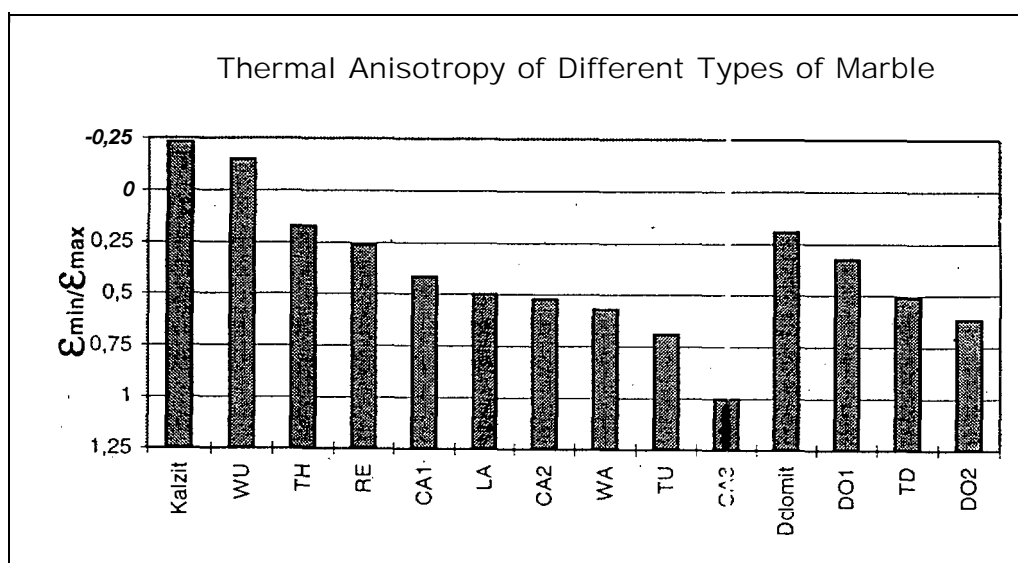
Various investigations in the laboratory and numerical simulations have proved the importance of grain size for the durability -of dimension of a particular type of marble. The markedness and the direction of the preferred orientation (texture) of the calcite grains in marble were found to be another important parameter.

### 4.3 Methods for Determining Durability of Dimension

For determining the parameters mentioned above, different methods can be used:

- **Thin-section petrography:** provides information on mineral composition, grain size, structure, as well as on possible interlocking at the grain boundaries. When using a universal stage, crystallographic preferred orientations can also be discerned.
- **Crystal optic methods:** the universal stage, the X-ray and the neutron texture goniometers, which were also tested within the scope of the project, are of rather academic interest only.
- **Ultrasonic velocity:** By means of ultrasonic velocity, the structure loosening can be measured. With strongly anisotropic materials, the ultrasonic velocity method is also suitable for determining the preferred orientation, but only if the method is calibrated by means of a dilatometer.
- **Mechanical behaviour:** The values of fracture energy, flexural strength and creeping behaviour are strongly dependent on the preferred orientation (variation of up to 40%). The breaking load of the dowel hole varies up to 15% depending on orientation. Therefore considering the preferred orientation is of utmost importance in marble production.
- **Frost-thaw cycles:** Various kinds of frost-thaw tests were performed. The influence of these frost-thaw cycles on dimension, fracture behaviour, flexural strength, water absorption and acoustic emission was investigated.
- **Dilatometer:** For determining the anisotropy of marble, a multiple dilatometer for measuring thermal expansion was specially developed. It provides the most precise results with a minimum effort. With only a few measurements the orientation and markedness of the texture can be determined 3-dimensionally.

Some types of marble showed an isotropic and others an anisotropic thermal expansion behaviour. The relation between minimum and maximum thermal expansion  $\epsilon_{\min} : \epsilon_{\max}$  amounted to between 1 and -0.15, according to the different types of marble. Figure 5 (below) shows the thermal anisotropy of 9 calcitic and 3 dolomitic types of marble.

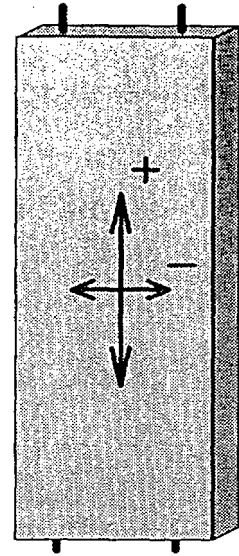


*Fig. 5: Ratio between minimum and maximum thermal expansion  $\epsilon$  in 9 calcitic and 3 dolomitic types of marble.*

In general, the maximum orientation of thermal expansion is not parallel to a block edge,

#### 4.4 Exploitation of Anisotropy (Texture)

Due to the extreme thermal behaviour of calcite, marble is most strongly anisotropic in thermal expansion. An analysis of residual dilatation after thermal cycling showed that the smallest residual dilatation (responsible for deformation) remains in the direction of the preferred orientation. Thus in rectangular panels the longitudinal axis should be oriented parallel to the crystallographic preferred orientation (see Fig. 6, right). The breaking load of the dowel hole also has the most favorable values if such an orientation is chosen.



*Fig. 6: recommended cutting direction for facade panels*

According to orientation, flexural strength values varied to up to factor 2. Floor panels should therefore be cut with their floor surface normal to the preferred crystallographic orientation-

#### 4.5 Physical Pre-Treatment

Investigations on a laboratory scale showed that physical pre-treatment of marble panels could increase their durability of dimension. These findings would have to be checked on a real scale, however, before making any recommendations regarding this pre-treatment.

#### 4.6 Climatologic Study

Damage on facade panels can be observed in northern as well as in central European regions, to a lesser extent also in Mediterranean countries. The traditional method of describing climatic conditions is to calculate average temperature values. There is, however, no direct causal relationship between the frequency of cases of damage and these average temperatures. Therefore, average temperature values do not supply sufficient information on the suitability of the climate in a particular region for certain types of marble. Much rather, daily temperature changes seem to play an important role, although the values for these changes are usually not supplied by meteorological institutes. In addition, daily temperature changes on facades are also subject to microclimatic influences (exposure to sun and rain; flow of air etc.).

Acoustic emission analyses during frost-thaw cycles furthermore showed that frost damage to marble mostly occurs in a temperature range around  $-10^{\circ}\text{C}$ . Therefore it does not appear to be particularly relevant how often a temperature cycle passes the  $0^{\circ}\text{C}$  boundary.

#### 4.7 Testing Programme for a Particular Type of Marble

From the numerous investigation methods tested, a testing programme was prepared containing those methods that are most cost-efficient and easy to carry out in practice. Under the condition of general weathering resistance, this testing programme provides information on the suitability of a particular type of marble when installed outdoors in a given microclimate (see Fig. 7, next page).

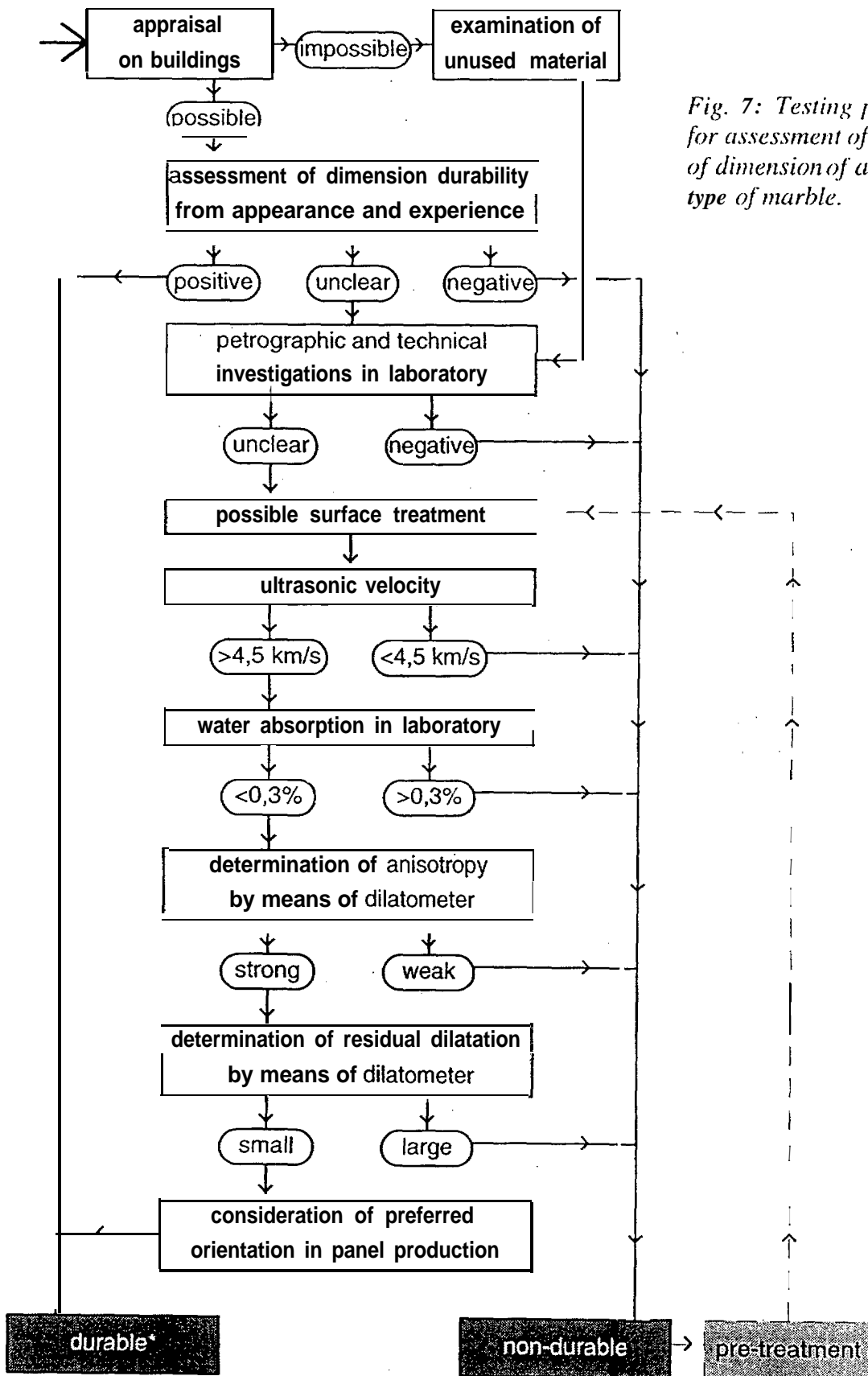


Fig. 7: Testing programme for assessment of durability of dimension of a pat-titular type of marble.

\*) under consideration of format, method of installation, surface treatment and local climate (only permissible in case of unambiguous identification of material)

## 5 Exploitation Plans and Follow-up Actions

### 5.1 Follow-up Activities

The *Working group for the Assessment of Stone Properties - WASP* has been set up at the Vienna University of Technology for carrying on the activities after the completion of the RTD-work on 31 December 1996. *WASP* shall in particular further develop the findings and the practical know-how gained in the testing of marble so far, and apply them to other types of natural stone in future.

*WASP* - contact addresses:

Institute for Geology, Vienna University of Technology  
Karlsplatz 13, A- 1040 Vienna, Fax: +43 1:044235

Walter Eppensteiner  
Tel. +43 1 58801 ext. 3283

Andreas Rohatsch  
Tel. +43 1 58801 ext. 3078

Institute for Applied and Technical Physics, Labor für Materialwissenschaften  
Vienna University of Technology  
Wiedner Hauptstraße 8- 10/1 37, A-1040 Vienna, Fax: +43 1 5868814

Elmar Tschegg  
Tel. +43 1 58801 ext. 3045  
e-mail: tschegg@atp6000.tuwien.ac.at

Clemens Widhalm  
Tel. +43 1 58801 ext. 5438  
e-mail: widhalm@atp3100.tuwien.ac.at

For extending the investigations to several stone parameters of different types of stone, and for improving dilatometer technology, further national and European research projects shall be proposed. In January 1997 the following two project proposals were already submitted to the EIJ's *Standards, Measurement and Testing (SMT)* programme:

- **Portable Universal Dilatometer - PUD:** development of a *PUD* for quick and comfortable use in practice, in order to be able to exploit the preferred orientation of marble in the production of marble panels.
- **Natural Stone Information System - NIS:** Departing from the most frequent causes of damage and the current regulations in CEN/TC246, extensions for the current standards shall be developed, in particular for the areas of anisotropy, durability of dimension, and E-module. The corresponding natural stone parameters shall be accessible in *NIS* via Internet.

In addition, the measures developed on a laboratory scale for increasing the durability of dimension of marble building components installed outdoors shall be tested *on* a real scale.

On the basis of the testing programme prepared (see 4.7), *WASP* is already offering materials testing for producers and users in the EU.

The findings represent the state-of-the-art in marble testing. Therefore *WASP* will work towards including these new findings in the negotiations on a harmonisation of European natural stone standards. Publications on this new state-of-the-art shall contribute to improving the quality and the image of marble as a cladding material, and to strengthening its competitiveness in the long run.

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