

POLITECNICO DI TORINO

Master of Science in Petroleum and Mining Engineering



Professional training report

Professional training at MarmoTest Laboratory

Student

277587 Alfio Di Giovanni

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Introduction

Carrara marble, its charm, its importance, its world fame... have always fascinated me and when the opportunity arose to carry out an internship at a company that worked with Carrara marble, I immediately took the opportunity and accepted this opportunity.

From 27 April to 15 June 2021, I did a curricular internship at MarmoTest, my company tutor was Stefano Bianchini. The professional training took place in the city of Carrara, at the headquarters of the aforementioned laboratory, with a full-time activity.

This professional training is part of the completion of the Master's Degree in Mining Engineering at the Polytechnic of Turin, followed by Prof. Marilena Cardu.

The professional training experience had different objectives, such as applied research work, carrying out laboratory tests, and "visits" to the quarry with the quarry manager to learn and know the world of marble quarries.

Mainly, my activity focused on analysing the performance of different resins to evaluate which of those studied was the most performing from the point of view of tensile and shear strength.

The resins are used today in the world of marble quarries to completely restore damaged blocks and to obtain, during the cutting phase, all the possible slabs, in perfect condition, thus increasing the productivity of the extraction site.

MarmoTest is a test laboratory, the only stone materials laboratory in Italy that operates with ASTM certified machines. This has made it possible to become the reference laboratory of the Renzo Piano Building Workshop, of FRONT and Guy Nordenson and Associates. It differs from other laboratories for the use of high-tech equipment and machines, which allow reaching very high standards and performances. Thanks to this equipment, MarmoTest is the only laboratory in the Apuo-Versiliese basin capable of performing low-cyclic fatigue tests in compression, bending, anchors and mock-ups, also necessary to simulate the effect of an earthquake.

MarmoTest carries out the tests required for the CE marking for internal and external cladding and flooring, curbs and sidewalks. MarmoTest is a member of the ASTM C-18 "Ornamental Stone" committee, in whose regulatory activity it participates. It carries out durability tests on ASTM standards and recommendations i.e., accelerated ageing tests with which it is possible to determine the physical-mechanical conditions of a finite ornamental stone exposed to the elements in a well-defined city and for a number of years chosen by the customer (usually 30 years). MarmoTest also performs "Bowing test" bending tests with the NT499 machine, specially designed to determine the ability of a stone to bend and therefore its possible use as an external coating.

The professional training allowed me to actively participate in all the activities that were included in the internship tasks, thus offering me a complete and interesting overview of the world of marble quarries, with its successes and limitations; as well as the work that is carried out in a marble testing and analysis laboratory.

Laboratory activity

The laboratory activity carried out in MarmoTest was dedicated to the study of the interaction between epoxy resins and stone materials. In particular, several Pull-Off tests were carried out to quantify the tensile stress, and subsequently also the shear stress, which causes the detachment of the dolly from the marble specimen, to which it was fixed.

The Pull off test, therefore, quantifies the adhesion strength of the epoxy resins used by identifying the breaking for traction load and/or shear load.

Pull-off test

The tensile pull-off method for adhesion testing involves glueing a test dolly to the coated surface and then pulling the dolly by exerting a force, which is perpendicular to the surface, in an effort to detach the dolly from the marble substrate. The tensile stress applied by the load cell increase gradually during the test. The value at which the debonds occurs, and the type of failure obtained, is recorded as a measure of the adhesion properties of the coating.

The marble coating to be examined is scraped with a grit paper, different dimension to evaluate how the results change, in terms of stress, varying this parameter. Then, the specimen is cleaned and an iron dolly is positioned above it in the case of the traction test or laterally in the case of the shear test, with a layer of epoxy adhesive between them to adhere to the surface. The dolly should be left in place for at least 24 hours before testing to allow the epoxy adhesive to dry and reach its best mechanical properties. Several aspects of the test method were assessed, including the mix of the epoxy glue, different types of resins, the surface condition, the design of the dolly, the condition of the marble and the dimension of the marble.

Specimen surface preparation

The tests were carried out on samples of marble from quarrying sites located in the Apuan Alps, in particular, is a "White Carrara Marble", a "Statuary White Marble" and other types of local marble.

Marble is a rock resulting from the metamorphism of sedimentary carbonate rocks, most commonly limestone or dolomite rock. Metamorphism causes variable recrystallization of the original carbonate mineral grains. Pure white marble is the result of the metamorphism of a very pure (silicate-poor) limestone or dolomite protolith. The characteristic swirls and veins of many coloured marble varieties are usually due to various mineral impurities such as clay, silt, sand, iron oxides, or chert which were originally present as

grains or layers in the limestone. These various impurities have been mobilized and recrystallized by the intense pressure and heat of the metamorphism.

In order to have an analysis that covered a greater field as regards the roughness of the marble support, several tests were carried out with different roughness of the material in order to also have data depending on this parameter. The roughness plays an important role because the resin enters the grooves of the marble and has a greater hold. The surface of the coating can be lightly abraded to promote adhesion of the adhesive to the surface. For this reason, the tests were carried out on smoothed and polished marble samples, scraped with the diamond disc, with 36 grit and 40 grit sandpaper through an angle grinder.



Figure 1 - Diamond disc



Figure 2 - 40 grit sandpaper



Figure 3 - 36 grit sandpaper

All the samples were subsequently cleaned with water to remove dust, grease, oils, etc., as it negatively affects the correct functioning of the test.

The specimens used for the tests were also conditioned in different ways to evaluate the influence of water. Mainly dry tests were carried out, but also wet tests. In particular, three types of conditioning with water were carried out:

- “Wet 1”: the specimen was immersed in water for a couple of hours before applying the resin and the dolly and subsequently kept out of the water,
- “Wet 2”: the specimen was immersed in water for a couple of hours before applying the resin and the dolly and then again immersed in water for 24 hours,
- “Wet 3”: the specimen was immersed in water for a couple of hours before applying the resin and the dolly and then again immersed in water for 24 hours but the water level covered the specimen for 3/4, so that, as is possible to see in the image below, the resin and the dolly were above the water level.



Figure 4 – “Wet 2” conditioning



Figure 5 - "Wet 3" conditioning



Figure 6 - "Wet 3" conditioning

Dollies

Dollies for pull-off adhesion testers are constructed in almost all the totality of iron, are a cylindrical component in which are created, by the blacksmith, the threaded holes to insert the screw for connecting the specimen to the load cell. The hole is performed in the upper face for the traction tests, and in the lateral surface for the shear tests. In both the case, the lower part of the dolly is fixed to the specimen. Two designs of dollies were used, one having a base width of 40 mm and the other a base of 50mm. For the shear test, only the dolly with a base of 50mm is used.

Dolly preparation typically consists of three important steps: degreasing, abrasion and cleaning. Degreasing refers to the removal of any trace oils or grease from the surface to be bonded. This may include oils from the skin of the person handling the dolly. Abrasion is an aggressive alteration of the profile of the dolly surface. Abrasion serves two primary purposes: to increase the available surface area for bonding and to remove any oxidation or rust. Cleaning is simply the removal of any loose particles from the surface to be bonded, particularly those created by abrasion.



Figure 7 - 40 mm dolly



Figure 8 - 50 mm dolly

Adhesive mixing

The test dolly should be glued to the surface using a suitable adhesive. In almost all the case, a two-pack epoxy adhesive is supplied with adhesion test units, only in a single case, a hybrid gel-adhesive is used.

The epoxy resins utilized are two components, resin and hardener, and each of them has its characteristics and its mix in weight or in volume, of the two components. All the instruction referred to the correct mix of the components are reported on the label on the package. To achieve a more accurate mix, in the case of the ratio between the resin and the hardener is evaluated in weight, the amount of each component was measured by using an accurate electronic balance.

There is no single glue that can be specified for all pull-off tests; rather, glue suitable for the conditions of the test should be used. The correct glue has bond strength greater than the adhesive strength of the coating being tested.

The traction tests were carried out by applying six different types of glue, four epoxy resins, one two-component organo-mineral resin and one hybrid gel-adhesive. Each of these has its weight or volume ratios which will be indicated below.

- The glue "A" is a two-component reactive, thixotropic epoxy resin that has a mix ratio of 1:1 by weight. The mixing is done manually or mechanically until thorough homogenisation.
- The glue "B" is an epoxy-based system, unfilled, solvent-free, thixotropic, with fast hardening. It consists of two components. Component 1 modified liquid epoxy resin, component 2 curing agent based on modified polyamines. The use ratio is 1:0.25 by weight and the mixing must take place until perfect homogenisation.
- - The adhesive "C" is a two-component epoxy resin, formed by the resin itself and the hardener with a mixing ratio of 1: 0.5 by weight, a thixotropic powder additive is added about 10% of the total weight of the mixture. The mixing is carried out manually or mechanically until complete homogenization.
- The adherent "D" is a two-component thixotropic resin, in a cartridge, the capsules are filled with a reinforced thixotropic polyester resin in one compartment and a catalysed mastic filler in the other, separated by a physical barrier.
- The glue "E" is a two-component organo-mineral resin, free of CFC and halogen. The two components, both liquids, must be mixed in a volumetric ratio equal to 1:1. After mixing the two components, the resin acquires instantly a high viscosity and a thixotropic behaviour.
- The adhesive "F" is a bi-component hybrid gel-adhesive. The pre-measured ratio of the two components is 8.6:1.4 by weight. Once the two parts are combined, a homogeneous mixing is carried out until a mixture of uniform consistency and colour is obtained.

Final configuration

After all the preparatory work and after 24 hours, the time necessary for the resin to harden, the test is ready to start. In the first two picture below is possible to see the configuration of the dry traction test, it shows the marble specimen in which is fixed the dolly. Figure 11 and 12 instead, show the “Wet 2” and “Wet 3” final configuration. Figure 13 and figure 14 show instead the dry shear configuration.



Figure 9 - Dry traction test configuration



Figure 10 – Dry traction test configuration



Figure 11 – “Wet 2” traction test configuration



Figure 12 – “Wet 3” traction test configuration



Figure 13 - Dry shear test configuration



Figure 14 - Dry shear test configuration

Testing machine

The testing machine is a "servo-controlled" machine, controlled by a real-time digital platform C-Rio with FPGA technology. The load is measured by a TCE load cell (5511 lbf of nominal load – linearity < 0.03%; hysteresis < 0.03%; repeatability < 0.01%). Load cell data acquisition (A/D) is performed by National Instruments NI 9237 24-Bit module. The sampling frequency is 10 milliseconds.

As is possible to see in the figure below, the system is composed of several components that are briefly described.



Figure 15 - System

1: Load cell

2: Adapter which connect the load cell to the rod end

3: Rod end with spherical plain bearing

4: System to connect the load cell to the dolly

5: Iron dolly

6: Iron plate

7: Clamp

The whole system is managed remotely from a PC on which, through the software AS_Pressa, connected to the press, the load cell is allowed to move up and down and therefore to bring the machine to the starting

position of the test. This software also allows for the evaluation of the deformations that occur in the specimen employing strain gauges, but this information was not necessary for my analysis and therefore was not used. The figure below shows the operator interface before starting the test. As is possible see from the image below, the software permits to see in real-time and records the load variation of the load cell in the box at the top left, to see and record the displacements, thanks to the strain gauges, in the lower-left part, and in the central part, a load-time graph is proposed.



Figure 16 - Software interface

To perform the pull-off test has studied a system to connect the dolly to the load cell thought ad adapter, a rod ends and at the low extremity with a screw that is screwed in the dolly to allow the machinery to apply the desired effort. An iron plate is placed on the specimen to allow the application of clamps to counteract the traction force applied by the machinery and allow the detachment of the dolly from the marble specimen.

The rod end consists of an eye-shaped head with an integral shank that forms a housing for a spherical plain bearing. This rod end present female (internal) threads that will be screwed to the load cell.

The clamps used in this test were four. One clamp 20cm long, two clamps 30cm long and the last one clamp 40cm long.

For the shear test was also used another iron plate in order to allow the clamps to anchor.

Results

The results achieved, as mentioned before, depending of course on the epoxy resin used or on the type of adherent, but if the same adhesive is used, the results are influenced by the condition of the specimen, in terms of water conditioning and also in terms of dimension of the grit sandpaper.

Types of breaks

Four types of rupture have been classified.

1. Adhesive failure: Coating adhesion strength exceeds the bonding strength of the adhesive.
2. Cohesive failure between adhesive and substrate: The bond strength of the adhesive exceeds the bond strength of the substrate.
3. Cohesive failure: Coating adhesion strength exceeds the bonding strength of the adhesive, till it reaches a breakage of the adhesive.
4. Substrate failure: The bond strength of the adhesive exceeds the bond strength of the substrate, till it reaches a breakage of the specimen. This is the desired break as it means the adhesive is suitable.

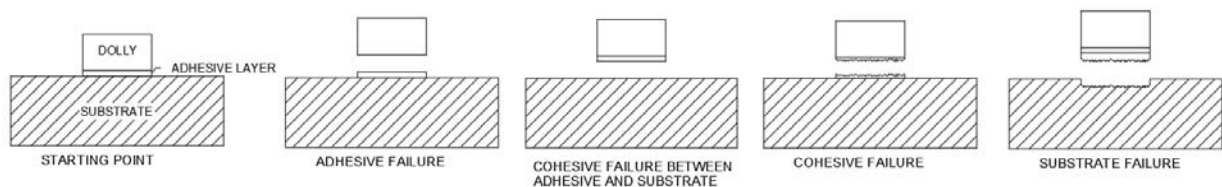


Figure 17 - Type of breaks



Figure 18 - Adhesive failure



Figure 19 - Cohesive failure between adhesive and substrate



Figure 20 - Cohesive failure



Figure 21 - Substrate failure

Resin A

Traction test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
1	35x10x3.5	Diamond disc	Dry	4	2.6	2.1	
2	35x10x3	Diamond disc	Dry	4	5.8	4.6	Unattached dolly, broken specimen
3	35x10x3	Diamond disc	Dry	5	4.0	2.0	Broken specimen
4	35x10x3	Diamond disc	Dry	5	5.2	2.7	Unattached dolly, broken specimen
5	35x10x3	Diamond disc	Dry	4	5.5	4.4	
8	35x10x3	Diamond disc	Dry	5	5.3	2.7	Broken specimen
9	35x10x3	Diamond disc	Dry	5	4.3	2.2	
10	35x10x3	Diamond disc	Dry	5	4.4	2.2	Broken specimen
11	35x10x3	Diamond disc	Dry	5	5.0	2.5	
12	35x10x3	Diamond disc	Dry	5	5.1	2.6	
					Average	2.8	
					Standard Dev.	0.9	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
1*	20x20x2	Polished	Dry	5	5.3	2.7	
2*	20x20x2	Polished	Dry	5	3.7	1.9	
4*	20x20x2	Polished	Dry	5	4.5	2.3	
13*	20x20x2	Polished	Dry	5	4.5	2.3	
					Average	2.3	
					Standard Dev.	0.3	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
3*	20x20x2	Acid-etched	Dry	5	1.7	0.9	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
6	35x10x3	Diamond disc	Wet 1	5	3.4	1.7	
7	35x10x3	Diamond disc	Wet 1	5	2.2	1.1	
					Average	1.4	
					Standard Dev.	0.4	

As it is possible to see in the table above, the tensile stress depends on the condition of the sample, dry or wet, and depends also on the dimension of the grit sandpaper. The major average tensile stress, 2.8 MPa, is reached when the specimen is tested in dry condition and it is scraped with the diamond disc because this treatment creates more roughness and the resin enters the grooves of the marble and has a greater hold.

The other two dry tests, polished and acid-etched, shows average tensile stress that is lower than the first case due to the different roughness of the surface; these respectively reach 2.3 MPa and 0.9 MPa.

As regards the test with water conditioned specimens, can be noted a decrease of 50% of the stress that causes the detachment of the dolly.

Resin B

Traction Test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
20	15x15x6	40	Dry	5	7.3	3.7	
21	15x15x6	40	Dry	5	4.8	2.4	
22	15x15x6	40	Dry	5	10.1	5.1	
23	15x15x6	40	Dry	4	6.7	5.4	
24	15x15x6	40	Dry	5	8.3	4.2	
25	15x15x6	40	Dry	5	6.5	3.3	
26	15x15x6	40	Dry	4	3.8	3.0	
32	20x20x3	40	Dry	4	3.4	2.7	
33	20x20x3	40	Dry	5	5.7	2.9	
					Average	3.6	
					Standard Dev.	1.1	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
20	15x15x6	Diamond disc	Dry	5	9.4	4.8	
21	15x15x6	Diamond disc	Dry	5	10.7	5.4	
22	15x15x6	Diamond disc	Dry	4	5.3	4.2	
23	15x15x6	Diamond disc	Dry	4	4.4	3.5	
24	15x15x6	Diamond disc	Dry	5	7.4	3.8	
25	15x15x6	Diamond disc	Dry	5	8.7	4.4	
26	15x15x6	Diamond disc	Dry	4	4.2	3.3	
32	20x20x3	Diamond disc	Dry	5	8.0	4.1	
33	20x20x3	Diamond disc	Dry	5	5.6	2.9	
					Average	4.0	
					Standard Dev.	0.8	

As it is possible to see in the table above, the major average tensile stress is reached when the specimen is tested in dry condition and is scraped with the diamond disc, the average value is 4.0 MPa. Instead, in the case when the dimension grit sandpaper is 40, the medium tensile stress is lower than the previous, and it is 3.6 MPa.

Shear Test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Shear strength [kN]	Shear stress [MPa]	Notes
27A	20x20x6	Polished	Dry	5	4.3	2.2	
27B	20x20x6	Polished	Dry	5	5.9	3.0	
27C	20x20x6	Polished	Dry	5	3.6	1.9	
27D	20x20x6	Polished	Dry	5	3.5	1.8	
28A	20x20x6	Polished	Dry	5	6.0	3.0	
28B	20x20x6	Polished	Dry	5	5.6	2.9	
28C	20x20x6	Polished	Dry	5	3.9	2.0	
28D	20x20x6	Polished	Dry	5	2.8	1.4	
29A	20x20x6	Polished	Dry	5	2.6	1.3	
29B	20x20x6	Polished	Dry	5	2.4	1.2	
29C	20x20x6	Polished	Dry	5	4.3	2.2	

29D	20x20x6	Polished	Dry	5	5.4	2.8	
31A	20x20x6	Polished	Dry	5	2.2	1.1	
31B	20x20x6	Polished	Dry	5	2.9	1.5	
31C	20x20x6	Polished	Dry	5	3.9	2.0	
31D	20x20x6	Polished	Dry	5	3.6	1.8	
					Average	2.0	
					Standard Dev.	0.6	

In the case of the shear stress, only the dry test with the polished surface of the spacemen are performed, and the average shear stress is 2.0 MPa.

Resin C

Traction Test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
1	35x10x3.5	40	Dry	5	4.2	2.2	Unattached dolly, broken specimen
5	35x10x3	40	Dry	5	4.1	2.1	Broken specimen
6	35x10x3	40	Dry	5	5.3	2.7	Broken specimen
9	35x10x3	40	Dry	5	4.9	2.5	Unattached dolly, broken specimen
12	35x10x3	40	Dry	5	5.2	2.7	Broken specimen
20	15x15x6	40	Dry	4	2.2	1.8	
21	15x15x6	40	Dry	5	8.5	4.3	
22	15x15x6	40	Dry	5	6.9	3.5	
23	15x15x6	40	Dry	5	9.5	4.9	
24	15x15x6	40	Dry	5	7.9	4.0	
7	35x10x3	40	Dry	5	5.7	2.9	Unattached dolly, broken specimen
10	35x10x3	40	Dry	4	4.6	3.7	
3*	20x20x2	40	Dry	5	3.1	1.6	Broken specimen
6*	20x20x2	40	Dry	5	3.7	1.9	Broken specimen

20	15x15x6	40	Dry	4	6.7	5.4	
21	15x15x6	40	Dry	5	10.6	5.4	
22	15x15x6	40	Dry	5	9.1	4.6	
23	15x15x6	40	Dry	5	5.4	2.7	
24	15x15x6	40	Dry	4	7.6	6.0	
27	20x20x6	40	Dry	4	6.0	4.8	
28	20x20x6	40	Dry	5	8.8	4.5	
29	20x20x6	40	Dry	5	8.9	4.5	
30	20x20x6	40	Dry	5	6.6	3.4	
20	15x15x6	40	Dry	5	6.9	3.5	
24	15x15x6	40	Dry	5	7.7	3.9	
					Average	3.6	
					Standard Dev.	1.3	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
20	15x15x6	36	Dry	4	3.4	2.7	
21	15x15x6	36	Dry	4	5.5	4.4	
22	15x15x6	36	Dry	5	7.8	4.0	
23	15x15x6	36	Dry	4	4.5	3.6	
24	15x15x6	36	Dry	5	7.9	4.0	
25	15x15x6	36	Dry	5	5.3	2.7	
26	15x15x6	36	Dry	5	9.1	4.6	
20	15x15x6	36	Dry	4	4.4	3.5	
21	15x15x6	36	Dry	4	5.1	4.0	
22	15x15x6	36	Dry	5	6.4	3.3	
23	15x15x6	36	Dry	4	3.8	3.0	
24	15x15x6	36	Dry	5	5.7	2.9	
25	15x15x6	36	Dry	5	6.6	3.3	
26	15x15x6	36	Dry	5	8.2	4.2	
3*	20x20x2	36	Dry	5	4.1	2.1	
6*	20x20x2	36	Dry	5	3.4	1.7	
					Average	3.4	
					Standard Dev.	0.8	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
27	20x20x6	Polished	Dry	4	6.5	5.2	
28	20x20x6	Polished	Dry	5	9.8	5.0	
29	20x20x6	Polished	Dry	5	6.0	3.1	
30	20x20x6	Polished	Dry	5	7.5	3.8	
31	20x20x6	Polished	Dry	5	7.2	3.7	
33	20x20x3	Polished	Dry	5	7.5	3.8	
					Average	4.1	
					Standard Dev.	0.8	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
32	20x20x3	Shiny	Dry	5	6.1	3.1	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
25	15x15x6	Diamond disc	Dry	5	8.4	4.3	
26	15x15x6	Diamond disc	Dry	4	9.9	7.9	
32	20x20x3	Diamond disc	Dry	5	9.6	4.9	
33	20x20x3	Diamond disc	Dry	5	7.3	3.7	
27	20x20x6	Diamond disc	Dry	5	6.8	3.5	
28	20x20x6	Diamond disc	Dry	5	7.4	3.8	
29	20x20x6	Diamond disc	Dry	5	8.0	4.1	
30	20x20x6	Diamond disc	Dry	5	7.3	3.7	
31	20x20x6	Diamond disc	Dry	5	4.8	2.5	
					Average	4.3	
					Standard Dev.	1.5	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
25	15x15x6	40	Wet 1	5	7.6	3.9	
26	15x15x6	40	Wet 1	5	5.4	2.8	
					Average	3.3	
					Standard Dev.	0.8	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
7	35x10x3	36	Wet 1	5	2.1	1.0	
10	35x10x3	36	Wet 1	5	2.7	1.4	
					Average	1.2	
					Standard Dev.	0.2	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
21	15x15x6	Diamond disc	Wet 2	4	0.3	0.2	
28	20x20x6	Diamond disc	Wet 2	5	0.3	0.1	
					Average	0.2	
					Standard Dev.	0.1	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
6*	20x20x2	Polished	Wet 2	5	1.9	0.9	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
30	20x20x6	40	Wet 3	4	1.4	1.1	
23	15x15x6	40	Wet 3	5	5.0	2.6	
25	15x15x6	40	Wet 3	4	4.7	3.7	
26	15x15x6	40	Wet 3	5	3.9	2.0	
					Average	2.4	
					Standard Dev.	1.1	

As it is possible to see in the table above, the tensile stress depends on the condition of the sample, dry or wet, and varying also changing the dimension of the grit sandpaper. The high average tensile stress, 4.3 MPa, is reached when the specimen is tested in dry condition, and it is scraped with the diamond disc because this treatment creates more roughness, and the resin enters the grooves of the marble and has a greater hold.

The other dry tests show average tensile stress that is lower than the first case due to the different roughness of the surface.

As regards the test with water-conditioned specimens, all three types of conditioning were performed, also varying the roughness of the surface of the specimen. As shown by the above data, it is noted that the condition in which there is the greatest stress is given by the condition in which the specimen is immersed in water only before the application of the resin, with stress of 3.3 MPa. Instead, in the cases in which the specimen was immersed in water for the entire drying time of the resin, the stress values are relatively low, less than 0.6 MPa on average.

Shear Test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Shear strength [kN]	Shear stress [MPa]	Notes
20A	15X15X6	Polished	Dry	5	5.9	3.0	
20B	15X15X6	Polished	Dry	5	4.5	2.3	
20C	15X15X6	Polished	Dry	5	9.3	4.8	Possible problem specimen anchoring
20D	15X15X6	Polished	Dry	5	6.6	3.4	
21A	15X15X6	Polished	Dry	5	5.6	2.8	
21C	15X15X6	Polished	Dry	5	8.3	4.2	Possible problem specimen anchoring
21D	15X15X6	Polished	Dry	5	8.9	4.5	Possible problem specimen anchoring
23A	15X15X6	Polished	Dry	5	4.9	2.5	
23C	15X15X6	Polished	Dry	5	8.3	4.2	Possible problem specimen anchoring
23D	15X15X6	Polished	Dry	5	10.6	5.4	Possible problem specimen anchoring
24A	15X15X6	Polished	Dry	5	10.7	5.4	Possible problem specimen anchoring

24B	15X15X6	Polished	Dry	5	6.5	3.3	
24C	15X15X6	Polished	Dry	5	10.3	5.3	Possible problem specimen anchoring
24D	15X15X6	Polished	Dry	5	8.7	4.4	Possible problem specimen anchoring
					Average	4.0	
					Standard Dev.	1.1	

In the case of the shear stress, only the dry test with the polished surface of the specimens are performed, and the average shear stress is 4.0 MPa, comparable with the tensile stress of the traction test. Probably these results are blown up because the anchoring system was not suitable for this type of test owing to the specimen during the test was raised slightly and therefore the support did not give the correct force to counterbalance the movement.

Resin D

Traction Test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
20	15x15x6	40	Dry	5	2.4	1.2	
21	15x15x6	40	Dry	5	2.4	1.2	
35	20x20x4	40	Dry	5	1.7	0.9	
39	20x20x4	40	Dry	5	3.0	1.5	
					Average	1.2	
					Standard Dev.	0.3	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
20	15x15x6	Diamond disc	Dry	5	6.2	3.2	
35	20x20x4	Diamond disc	Dry	5	2.5	1.3	
39	20x20x4	Diamond disc	Dry	5	3.5	1.8	
41	10x20x7	Diamond disc	Dry	5	3.1	1.6	
42	20x20x3	Diamond disc	Dry	5	3.4	1.7	
					Average	1.6	
					Standard Dev.	0.2	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
41	10x20x7	Polished	Dry	5	3.6	1.8	
45	10x20x7	Polished	Dry	5	5.2	2.6	
					Average	2.2	
					Standard Dev.	0.6	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
42	20x20x3	Shiny	Dry	5	0.6	0.3	
43	20x20x3	Shiny	Dry	5	0.2	0.1	
43	20x20x3	Shiny	Dry	5	0.8	0.4	
					Average	0.2	
					Standard Dev.	0.2	

For this type of resin are performed the only dry test and the result reported in the table above shows that the case in which the specimen is polished reach the high tensile stress, 2.2 MPa. The lower stress is recorded in the case of the shiny surface due to the fact that the roughness of this surface is very low and so the resin didn't attach well.

Shear Test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Shear strength [kN]	Shear stress [MPa]	Notes
22A	15X15X6	Polished	Dry	5	3.1	1.6	
22B	15X15X6	Polished	Dry	5	2.0	1.0	
25A	15X15X6	Polished	Dry	5	2.6	1.3	
25B	15X15X6	Polished	Dry	5	4.5	2.3	
26A	15X15X6	Polished	Dry	5	3.9	2.0	
26B	15X15X6	Polished	Dry	5	3.8	1.9	
30A	20x20x6	Polished	Dry	5	1.4	0.7	
					Average	1.6	
					Standard Dev.	0.6	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
22C	15X15X6	Diamond disc	Dry	5	5.0	2.5	
22D	15X15X6	Diamond disc	Dry	5	4.5	2.3	
26C	15X15X6	Diamond disc	Dry	5	4.6	2.3	
					Average	2.4	
					Standard Dev.	0.1	

In the case of the shear stress, only the dry test is performed, but in this case are evaluated two different specimen surface condition, one surface polished and the other one scraping with the diamond disc. The average shear stress for the first configuration is 1.6 MPa, instead for the second one is 2.4 MPa.

As in the case of the tensile test, also in the shear test, the condition in which there is greater stress is when the surface of the specimen is scrape with the diamond disc.

Resin E

Traction test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
23	15x15x6	40	Dry	5	3.9	2.0	
24	15x15x6	40	Dry	4	1.6	1.3	
27	20x20x6	40	Dry	5	2.3	1.2	
28	20x20x6	40	Dry	4	1.2	0.9	
29	20x20x6	40	Dry	5	3.7	1.9	
20	15x15x6	40	Dry	5	1.9	1.0	
21	15x15x6	40	Dry	5	2.1	1.1	
22	15x15x6	40	Dry	5	1.0	0.5	
23	15x15x6	40	Dry	5	2.8	1.4	
24	15x15x6	40	Dry	4	0.7	0.5	
25	15x15x6	40	Dry	4	0.5	0.4	
26	15x15x6	40	Dry	5	3.7	1.9	
27	20x20x6	40	Dry	5	1.4	0.7	
28	20x20x6	40	Dry	5	1.7	0.9	
29	20x20x6	40	Dry	5	2.0	1.0	
30	20x20x6	40	Dry	4	2.1	1.7	
31	20x20x6	40	Dry	5	1.8	0.9	
32	20x20x3	40	Dry	5	1.7	0.9	
33	20x20x3	40	Dry	5	2.4	1.2	
					Average	1.1	
					Standard Dev.	0.5	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
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20	15x15x6	40	Wet 1	5	0.5	0.3	Resin not fixed
22	15x15x6	40	Wet 1	5	0.1	0.1	Resin not fixed
25	15x15x6	40	Wet 1	5	0.2	0.1	Resin not fixed
26	15x15x6	40	Wet 1	5	0.5	0.3	Resin not fixed
					Average	0.2	
					Standard Dev.	0.1	

The test performed with this resin exhibit that the average tensile stress, in dry condition with a dimension of the grit sandpaper equal to 40, is 1.1 MPa, and it is lower than all the others resin used in the same conditions. In the case of the wet condition, the only test done is the first wet configuration, and the results achieved shows that the stress is too low, This behaviour is because the resin is not fixed on the specimen, so other tests are not carried out.

Hybrid gel-adhesive F

Traction test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
20	15x15x6	Diamond disc	Dry	4	5.6	4.4	
21	15x15x6	Diamond disc	Dry	5	9.0	4.6	
23	15x15x6	Diamond disc	Dry	5	9.7	5.0	
24	15x15x6	Diamond disc	Dry	4	5.9	4.7	
31	20x20x6	Diamond disc	Dry	5	9.2	4.7	
21	15x15x6	Diamond disc	Dry	5	3.7	1.9	
					Average	4.2	
					Standard Dev.	1.2	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
34	20x20x4	Polished	Dry	5	5.7	2.9	
35	20x20x4	Polished	Dry	5	6.3	3.2	
36	20x20x4	Polished	Dry	5	7.2	3.6	
37	20x20x4	Polished	Dry	5	6.7	3.4	

38	20x20x4	Polished	Dry	5	8.0	4.1	
39	20x20x4	Polished	Dry	5	7.1	3.6	
40	15x15x4	Polished	Dry	4	5.5	4.4	
34	20x20x6	Polished	Dry	5	6.7	3.4	
36	20x20x4	Polished	Dry	5	3.4	1.7	
37	20x20x4	Polished	Dry	4	2.1	1.7	
38	20x20x4	Polished	Dry	5	4.9	2.5	
39	20x20x4	Polished	Dry	4	1.7	1.3	
					Average	3.0	
					Standard Dev.	1.0	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
20	15x15x6	Diamond disc	Wet 1	5	3.4	1.7	
24	15x15x6	Diamond disc	Wet 1	5	6.5	3.3	
					Average	2.5	
					Standard Dev.	1.1	

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Tensile strength [kN]	Tensile stress [MPa]	Notes
35	20x20x4	Polished	Wet 1	5	4.0	2.0	
40	15x15x4	Polished	Wet 1	4	2.5	2.0	
					Average	2.0	
					Standard Dev.	0.0	

The results achieved in both the conditioning configuration, dry or wet 1, shows that the higher results in terms of tensile stress are obtained when the surface is scraping with the diamond disc and they are respectively 4.2 MPa for the dry test and 2.5 MPa for the wet case.

Shear test

Sample Number	Dimensions [cm]	Dimension grit sandpaper	Conditioning	Φ Dolly [cm]	Shear strength [kN]	Shear stress [MPa]	Notes
22A	15X15X6	Polished	Dry	5	4.8	2.4	
22B	15X15X6	Polished	Dry	5	4.3	2.2	
22C	15X15X6	Polished	Dry	5	3.5	1.8	
22D	15X15X6	Polished	Dry	5	4.2	2.1	
25A	15X15X6	Polished	Dry	5	5.8	2.9	
25B	15X15X6	Polished	Dry	5	6.4	3.3	
25C	15X15X6	Polished	Dry	5	3.9	2.0	
25D	15X15X6	Polished	Dry	5	3.7	1.9	
26A	15X15X6	Polished	Dry	5	6.2	3.2	
26B	15X15X6	Polished	Dry	5	4.5	2.3	
26C	15X15X6	Polished	Dry	5	3.3	1.7	
26D	15X15X6	Polished	Dry	5	3.6	1.8	
30C	20x20x6	Polished	Dry	5	2.8	1.4	
30D	20x20x6	Polished	Dry	5	3.6	1.9	
					Average	2.2	
					Standard Dev.	0.6	

In the case of the shear stress, only the dry test with the polished surface of the specimens are performed, and the average stress is 2.2 MPa.

Comments of the results

It is clear from this series of tests that the results can be significantly affected by minor variations in one or more of the test steps. From the choice of adhesive, through the preparation of the coating surface and the test dolly, the test must need to be precise and consistent. This allows results for the same coating under different conditions or different coatings under the same conditions to be compared with confidence.

Nevertheless, the results obtained show, as previously mentioned, that the stress that causes the detachment of the dolly depends on the conditions of the specimen, ie dry or wet, and also on the roughness of the surface on which the dolly is attached.

For both tensile and shear tests, the condition in which higher stress values were obtained is those in which the specimen was dried and abraded with the diamond disc. In particular, the adhesive that recorded the