Itria Valley (Apulia, Italy): Comparison of limestones for the construction and restoration of “Trulli” roofing

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Abstract

The high concentration and cultural relevance of dry-built constructions in a territory such as Itria Valley, in Apulia (southern Italy), which was designated a World Heritage Site by UNESCO in 1996, make such constructions especially valuable, and raise the matter of conservation through the accurate selection and treatment of natural stone materials. The original and traditional way of construction (more precisely, the roofing of trulli) relies on the use of flat stones, 'chiancarelle', which are commonly taken from local accumulations ('specchie') or quarried from shallow embankments. Recently, the trend has shifted towards the use of sawn stones, which are less expensive since they do not need to be shaped by artisans. The scope of this study is to compare the mechanical performance of chiancarelle and sawn stones, to find whether correlation trends can be found between the technological properties of such stones, and to assess whether ageing cycles can produce variations in the mechanical behaviour of sawn stones. Finally, the results obtained allow the identification of the tested material and its geological origin, as well as the correlation with mechanical and technological properties.

Keywords: Limestones; Late Cretaceous; Mechanical performance; Weathering resistance; Accelerated ageing; Ultrasound pulse velocity.

1. Introduction

In the last years the attention to heritage stones developed in two main directions: to find and to apply innovative solution to protect the stone historically used for monuments and buildings (Baglioni et al. 2021, Croce 2021, Chelazzi et al. 2108, Rosewitz, and Rahbar, 2018, Toniolo and Gherardi 2018) and to recognize and protect the heritage stone widely employed in a territory qualifying by means of physical and mechanical properties and referring to the old and recent quarries (Kaur et al. 2021, Cardenes et al. 2021, Freire Lista et al. 2021, Castro et al. 2021). Concerning the Apulia territory and its traditional buildings, the few international publications have the goal to increase the knowledge of a widespread and unique heritage but detailed information on stone and quarry both of Trulli and of other traditional building constructions are not given. The Apulian limestones wholly constitute the historic building constructions of the "Regione Puglia" (in the south of Italy) named Trulli (representing an outstanding universal value for UNESCO (https://whc.unesco.org/en/list/787)), but they are also present in other stone buildings of the well-known Itria Valley. The *Trulli* are drywall (mortarless) constructions made of roughly worked limestone blocks collected from neighbouring fields. These kind of historical buildings, characterized by a quadrangular shape and a conical roof, from the fourteenth century were used mainly as settlements for temporary housing or agricultural storage. Nowadays are widely used as buildings for farm holyday as well as summer residence. The analysis and characterization the stones employed in the Trulli and the study of their origin represents a step forward the enhancement and valorization of Apulian stone heritage.

1.1 The importance of the "Trulli" constructions

Apulia (southern Italy) is mostly made up of limestone, which represents a durable and precious resource. The most common rural constructions, 'Masserie' and 'Trulli', represent a significant element of the Cultural Heritage of the territory, as an example of traditional human settlement and evidence of traditional commerce and rural activities (Romanazzi, 2017). In particular, the 'Trulli of Alberobello' have been listed as a UNESCO World Heritage Site since 1996 (Samalavičius and Traškinaitė, 2021). An exceptional display of such dry-built constructions is in the municipality of Alberobello – Itria valley (Bari), the most evident example of an aggregation of trulli in Apulia, (Figure 1), where Trully are more then 1500 units (https://whc.unesco.org/en/list/787/) . The number of trulli is a reflection of their impact on the local cultural heritage, as they define a clear cultural identity. In the 15th century, to avoid taxation of urban settlements, the Counts of Conversano insisted that buildings should be dry-built, in order to result as temporary constructions (Chirulli, 1983). The efforts of local farmers led to these cone-shaped habitations, made exclusively out of local material. This push to adaptation, but rooted in tradition, is, perhaps, the most significant aspect of trulli; the name itself is derived from the Greek "*troulloz*" (troullos) (Marzulli, 2019), which can be translated as 'dome' and refers to prehistoric stone constructions named tholos, which were very common in the Mediterranean region. The connection of trulli with strong local heritage is a hint as to how deep the architecture is rooted in local culture; there would be no Alberobello and Itria Valley without its farmers, there would be no farmers without the trulli, and there would be no trulli without natural stone which, therefore, represents a fundamental element in the identity of the territory.

Figure 1: Satellite image (Sentinel2) and GIS: it is possible to outline the borders of Itria Valley, based on the indications of territorial plans of the Apulia Region (PPTR Part 7, 2015; sit.puglia.it, 2021).

The stone materials differ in the method of extraction: chiancarelle are traditionally taken from local accumulations, named 'specchie' (Marzulli, 2019) (Figure 2a), whereas modern sawn stones are quarried like any other construction material (Figure 2b), and not necessarily from the same geological levels that chiancarelle belong to. The aim of this study is to draw comparisons and correlate the characteristics of chiancarelle, the flat stones traditionally employed for the roofing of trulli, and more recent alternatives, represented by quarried and sawn stones.

Figure 2: on the left) A ‘specchia’, a local cluster of natural stone, one of the possible sources of the chiancarelle (Marzulli M., 2019); on the right) Sawn stones from Palmisano quarry in Alberobello.

Recently, there has been a shifting trend towards the use of sawn stones (Figure 3a), coming directly from local or overseas quarries; materials can be delivered ready-cut and shaped, and all stones are identical in shape. This represents a less expensive alternative to the use of natural chiancarelle, which requires the manual work of a Mastro Trullaro, who manually selects stones from either specchie or substrata of the terrain, following a methodology that is passed on from a generation of artists to the next. The latter methodology is becoming more and more uncommon, along with the artistic profession of shaping chiancarelle by hand with delicate hammer strokes; the work of a Mastro trullaro is intrinsically imperfect and allows each single trullo to be different from any other, with stones that always differ both in terms of dimensions and shape (Figure 3b).

Figure 3: on the left) a modern building with sawn limestones replacing traditional chiancarelle of the roof (cortesy of arch. Intini 2020); on the right) a typical trullo in Itria Valley.

1.2 Geological framework

The limestones of Itria Valley corresponding to different sedimentation environments and different geological ages (geological series), which can be recognised by the presence of specific fossils. These limestones belong to the Late Cretaceous (from Late Barrenian to Turonian age, about 30 million years ago) series of Bari, Altamura, Ostuni and Caranna, and are very prolific in terms of the extraction of limestone, quarried both as an aggregate for construction and for ornamental purposes in rural buildings and churches. Chiancarelle can be quarried from the area between the Bari and Altamura Series (specifically from the Sannicandro level, characterised by the presence of the Macro-Foraminifera Cisalveolina Fallax (Maggiore 1983)), or gathered from local accumulations. They are traditionally used for the construction of the cones of the trulli. These stones can be classified as strongly stratified stromatolitic limestones, sometimes affected by karstification (Reina and Buttiglione, 2005). By studying the geological maps (Carta Geologica d'Italia, 1971) and researching quarry sites (Figure 4) (Reina and Buttiglione, 2005), it was possible to reconstruct the pattern of the lithostratigraphic series and the surface series. Altamura Limestone outcrops across most of Itria Valley, and aggregate materials are mainly extracted from it, especially for road building, although some varieties of ornamental stones (namely Pietra Gentile) can also be found, at times.

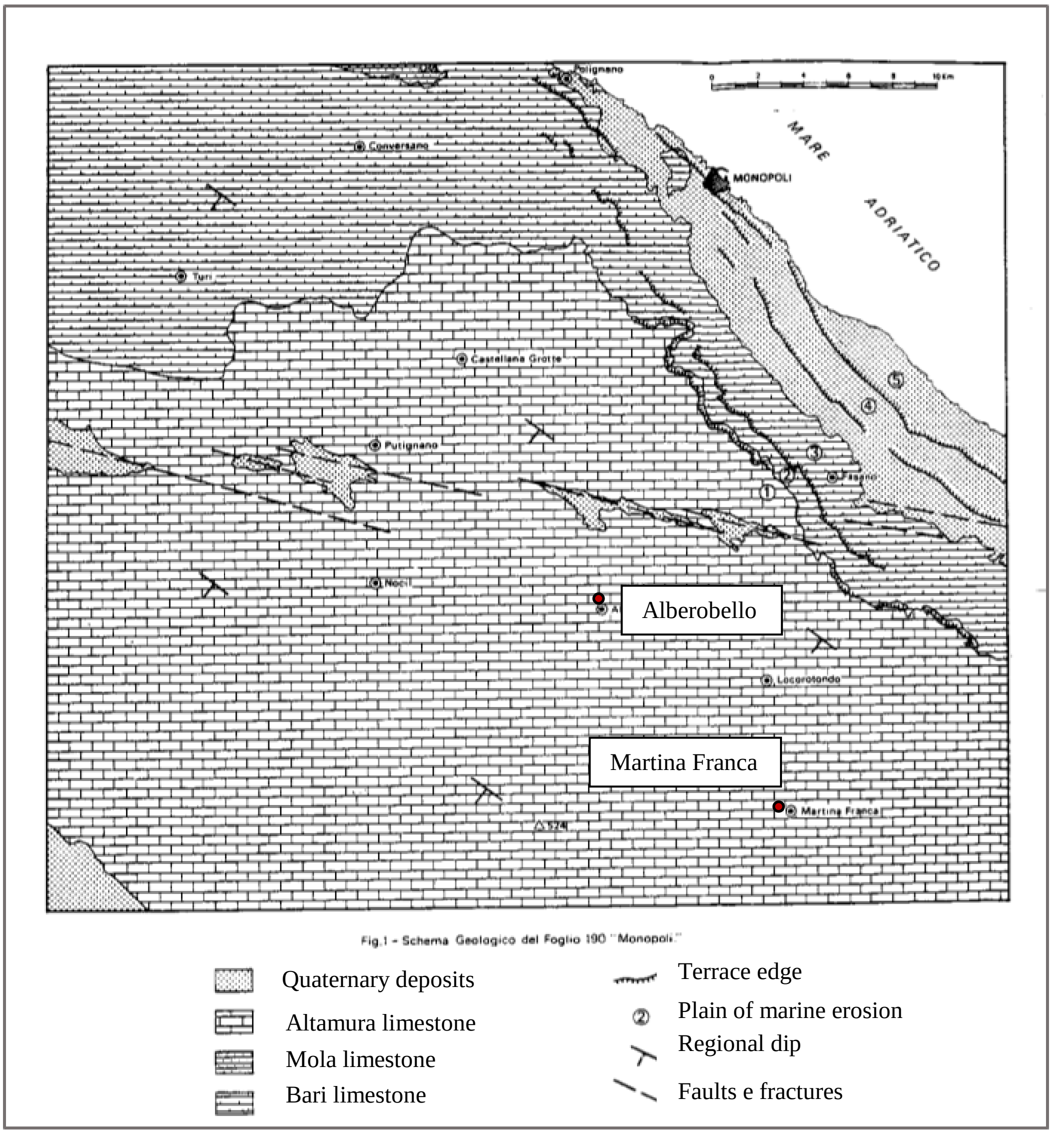

Figure 4: The geological map of Itria Valley. Altamura Limestone represents the main geological formation (Carta Geologica d'Italia, 1971)

The level of the Bari Limestone is more ancient and presents some of the most renowned varieties of natural stone for ornamental purposes: Perlato Svevo, Filetto Rosso Jonico and Cocciolato. These stones, shown in Figure 5, have been studied in the literature (Maggiore, 1983) and provide a solid base for the comparison of mechanical properties of the specimens analysed in this work.

Figure 5: From left to right Filetto Rosso Jonico; Perlato Svevo; Cocciolato ornamental sotnes. Fossil dimensions can range between 5 and 20 mm. (Cotecchia et al., 1982).

2. Materials and methods

2.1 Chemical background

The materials tested in this work belong to the limestone series of Bari and Altamura (Late Cretaceous). As a reference, the chemical composition of similar materials, estimated on 14 sample collected and analysed, is presented in Table 1 (Borghi, 1993). These materials have been collected at a quarrying site near Polignano (Bari), and can be considered representative to give a solid background of the chemical composition limestones in Murgia dei Trulli, since they can all be classified as pure limestones (other works, such as Fiorucci, 1982, have dealt with chemical analyses of Murgia limestones, especially in the area of Ostuni, confirming this), as they are mostly composed of CaO and CO2. For the other oxides and elements the obtained values are very variable and for this reason, even if on 14 samples, the mean values are not significant. For a better understanding of the analyzes, references to the measurement intervals and therefore to the minimum and maximum values have been added.

Table 1: Composition (mass percentage) of samples taken from a quarrying site near Polignano (Bari) from Borghi (1993).

Oxides				
	Minimum value (%)	Maximum value (%)	Mean Value (%)	Standard Deviation (%)
SiO_2	0.04	4.39	1.15	1.72
TiO_2	0.02	0.11	0.04	0.03
Al_2O_3	0.08	2.23	0.67	0.86
Fe_2O_3	0.07	5.61	1.02	1.88
CaO	33.66	55.63	47.27	8.74
Na_2O	0.01	0.07	0.02	0.02
CO_2	38.34	47.39	43.22	2.18
MgO	0.32	18.97	5.26	7.46
H_2O	0.06	1.64	0.85	0.64
Elements				
	Minimum value (ppm)	Maximum value (ppm)	Mean Value (ppm)	Standard Deviation (ppm)
Cl	57	1900	331	520
S	164	720	328	181
Rb	4	25	11	8
Sr	43	266	152	78
Ba	1	102	20	34
Ce	8	25	9	10
Y	6	19	10	4
Cu	11	20	17	5
Zn	4	31	7	11
Ni	7	36	21	16
Cr	4	35	11	9
V	2	187	44	66
Zr	3	26	6	8

2.2 In situ tests

In situ tests were conducted by means of ultrasonic pulse measurements (UPV) on several buildings of interest, as UPV measures proved to be a valid way of assessing the properties of natural stone, both on-site (Vasanelli et al., 2017) and in the laboratory (Eljufout and Alhomaidat, 2021). The on-site tests performed for this work particularly focussed on a 19th century trullo in Martina Franca (Figure 6), to draw a comparison between natural and aged chiancarelle and quarried sawn stones, like those coming from a quarry near Alberobello.

Figure 6: On site tests performed through UPV measurements on relevant cultural buildings, such as Trullo Palmullo, built in the first years of 1800 in Martina Franca. In this figure, a measurement is being taken on the cone of a trullo.

The investigation performed on site consisted of indirect UPV measurements. By positioning the instrumentation (exponential transducers with 33 kHz frequency) on the stone, the velocity of the medium is reconstructed through a linear regression between the position of the transducers and the first-arrival-time signals. To execute the velocity estimation correctly, adjustments to the gain and voltage of the ultrasonic signal are often necessary. This method of testing is especially valuable for on-site campaigns, since it produces a near-immediate estimation of the material velocity and is completely non-invasive; in this way, the integrity of the stone material can be preserved, which is of paramount relevance in the study of cultural heritage.

2.2 Laboratory tests

The materials tested in this study were collected and extracted from two sources:

1) The Palmisano Quarry, near Alberobello (40°46'23.73" lat, 17°12'55.89" lon), which extracts natural stone for building construction and roofing; ten 50 x 50 x 50 mm cubes and twenty 15 0x 50 x 30 mm bar specimens from this location were signed as P ALB and their progressive number (Figure 7).

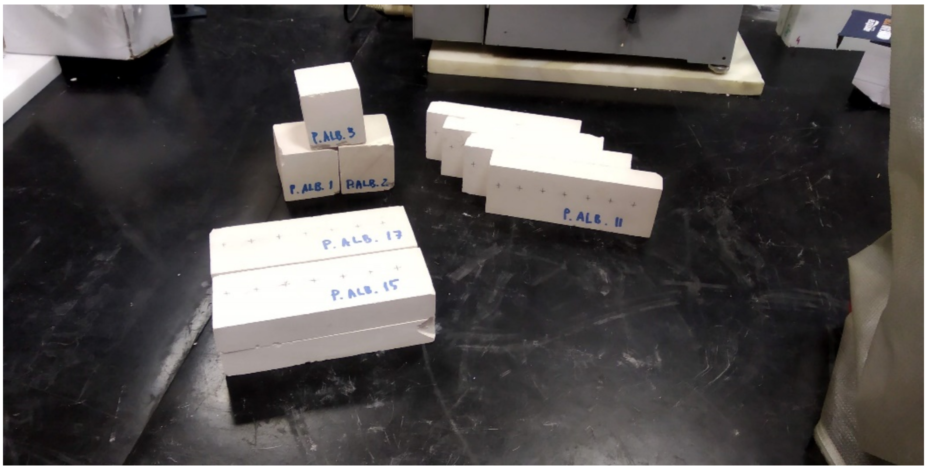

Figure 7: The stone specimens from Palmisano Quarry, outside Alberobello, coded P ALB. This quarry sells sawn stones for the use of chiancarelle, along with materials for construction and roofing.

2) Trullo Palmullo (40.39’45.9’’ lat, 17.23’50.2’’ lon), a 18th (beginning of 19th) century trullo; twelve specimens (125 x 50 x 25 mm) (Figure 8) were coded TPI A and five TPI B; they were cut from a single stone block but presented evident alteration and signs of lichen attack on one half (part A) (Figure 9). The reason for the distinction was to study whether weathering on the surface of the stone can produce recognisable effects in the mechanical properties.

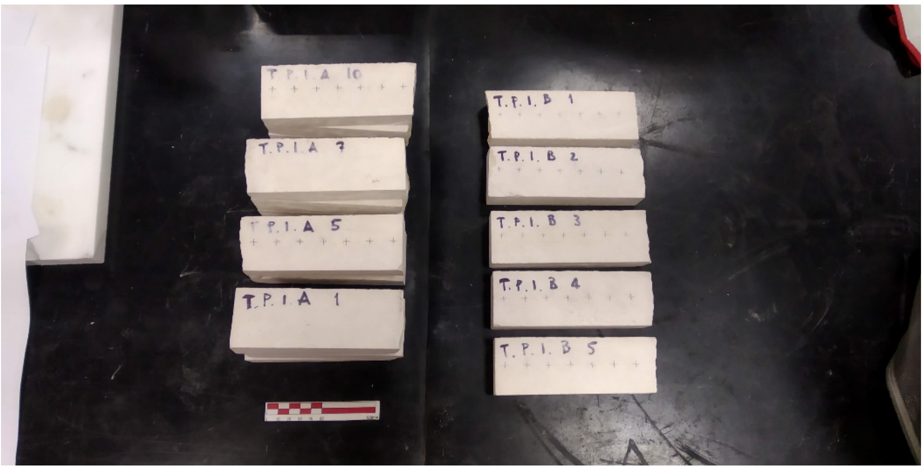

Figure 8: The specimens cut from the chiancarella gathered from Trullo Palmullo (Martina Franca). They are divided into group TPI A and TPI B: TPI A specimens come from the unaltered part of the chiancarella, while TPI B come from the superficially weathered half.

Figure 9: One half of this stone from Trullo Palmullo (in this case a chiancarella and not a sawn stone) shows evident signs of superficial weathering, which may be linked to mechanical properties. In this figure, taken before cutting, T. PALM. INT.1 refers to the TPI A side, whereas T. PALM. INT. 2 refers to the TPI B side.

The laboratory analyses included: petrographic characterisation of the stone samples on thin section specimens prepared according to EN 12407 and carried out through a polarising optical microscope and a digital camera, to visualise the images on a PC. The thin sections had a thickness of about 30 μm. Ultrasound Pulse Velocity (UPV) tests (EN 14579) were carried out in indirect mode, with 33 kHz exponential transducers and a regular step of 2 cm. The other tests were water absorption (WA) at atmospheric pressure (EN 13755); open porosity (pO) tests (EN 1936); flexural strength (R_{tf}) under concentrated load tests (EN 12372); thermal shock (EN 14066) and accelerated ageing tests; analysis of the spatial distribution of mechanical properties inside a single stone (this analysis was performed only on the chiancarella of Trullo Palmullo, to study whether superficial weathering could sensibly alter the mechanical response of the medium). Due to the limited volume of available material, the dimensions of the cut specimens were not in complete compliance with the standards. The main goal was to obtain a statistically representative number of specimens to be tested with the above-mentioned procedures. In particular:

3) For WA and pO tests, the key parameter of surface/volume ratio was respected, as expressed in EN 13755.
4) In flexural strength tests, the layout of the loading cell (namely the distance between supporting rollers) was compliant with the indications of EN 12372.
5) For UPV tests, the 33 kHz exponential transducers were chosen to have measurements comparable with those obtained in situ, even though the dimensions of the specimens would be more adequate for higher-frequency transducers.

2.2 Accelerated ageing tests

The tests for accelerated ageing were conducted in not standardized conditions. The procedure that was followed to perform thermal and moisture cycles was not completely in accordance with what is prescribed by the European reference standard, EN 16306; however most of the precautions taken, come directly from it. The test was planned and carried out according to a previous research performed on limestones from Sardinia, to simulate Mediterranean climatic conditions in a faithful way and model the ageing of the material (Sitzia et al., 2020). The objective was to simulate an appropriate degradation of the stone samples, through fifty 12-hour cycles, with temperatures ranging from 20 to 80°C and a constant moisture of 100% (Figure 10). Under these conditions, the intended simulated ageing was about 300 days, i.e. about four years of effective summer conditions (referring to the average forecast data of temperature and humidity of several cities in the Itria Valley for the months of June, July and August 2020). In these conditions a drop in technological performance was expected, as thermal ageing tests were proved to cause sensible variations in mechanical response (Fioretti and Andriani, 2018).

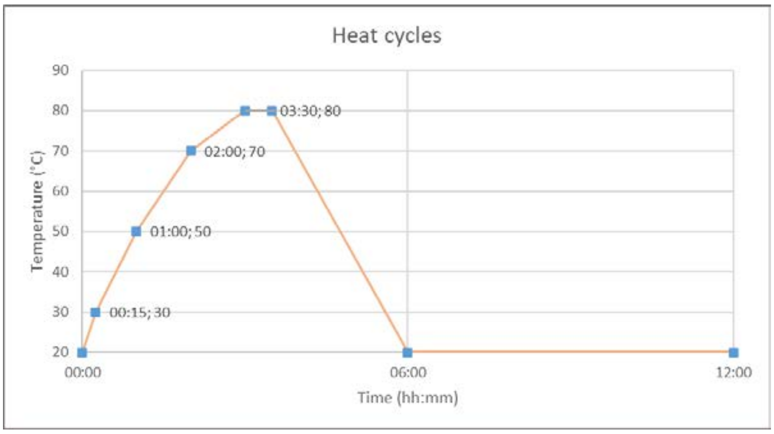

Figure 10: The heat cycles were performed over a 12-hour period with a constant humidity of 100% and conducted only on the specimens from Palmisano Quarry.

2.3 Spatial distribution of mechanical properties inside the chiancarella from Trullo Palmullo

After the UPV and flexural strength tests were performed on the samples sawn from the chiancarella, the specimens were rearranged to shape the original sample (Figure 11), in order to verify whether mechanical properties have a spatial distribution inside the single stone, which could depend on several factors, including the superficial weathering caused by atmospheric agents and lichen/mold attack (as is evident in Figure 9). After the reconstruction of the stone, four different areas could be identified (Figure 11). The difference in the between the different areas will be compared with the physical and mechanical characteristics tested by means of the measure of UPV and flexural strength (Table 6).

Figure 11: The upper layer of the chiancarella includes samples TPIA 1 to 6, while the lower one contains TPIA 7 to 12.

3. Results of on-site and laboratory tests

3.1 Mechanical and technological properties tests

In the Table 2 and Table 3 are reported the results respectively of on-site tests on the base and the roofing Trullo Palmullo and laboratory tests on the specimens cut from the roofing of that ancient Trullo (TPIA and TPIB according to caption of Figure 9) and on the specimens from Palmisano quarry (P ALB). The values indicated are the arithmetic means and standard deviations. The measurements of UPV are rounded to the nearest 10 m/s, while WA, pO and R_{tf} are rounded to the first decimal figure.

Table 2: The results of on-site tests on Trullo Palmullo: the UPV values will be compared to those recorded in the laboratory.

NAME	Location	UPV (m/s)
Trullo Palmullo	Base	2350
	Cone	1990

Table 3: The mean values and standard deviations of UPV, WA, pO and R_{tf} for the groups of specimens.

CODE	UPV (m/s)	WA (%)	pO (%)	R_{tf} (MPa)
P ALB natural condition	2210 ±117	4.4 ±0.9	13.9 ±2.8	11.4 ±4.2
TPI A	2070 ±192	5.9 ±1.9	14.6 ±3.3	15.1 ±3.4
TPI B	2340 ±87	3.7 ±1.4	11.3 ±2.6	15.7 ±4.7

3.2 Accelerated ageing tests

The aged stone samples were tested with UPV and flexural strength measures; the results are reported in Table 4.

Table 4: Mean and standard deviations of the measurements of UPV and flexural strength performed on aged specimens, through thermal shock and conditioning cycles of temperature and moisture.

METHOD	UPV (m/s)	Rtf (MPa)
Thermal shock	2290 ± 116	13.7 ± 1.2
Thermal/moisture cycles	2290 ± 39	13.4 ± 1.1

By comparing the values of UPV and mainly of R_{tf} of the samples from Palmisano Quarry before and after accelerated ageing (cfr. table 3), it can be observed that really different from the expected ones., as UPV more or less maintain the value of the natural conditions but the flexural strength values show an increase in the mean value, getting closer to the 15.4 MPa of the old stone of Trullo Palmullo. These results lead to some considerations:

- the accelerated ageing procedures were not aggressive enough, therefore, they did not produce the expected effects of sensible (about 10 to 15%) loss of mechanical properties (Sitzia et al., 2020).
- the stone material shows a resistance to weathering.
- this kind of limestone could increase its resistance to flexural strength with the ageing.

These explanations can be investigated further, through more testing. Visual observations for the evaluation of the effects of accelerated ageing were conducted, to detect colour changes of the samples, following EN 16140 (Figures 12 and 13).

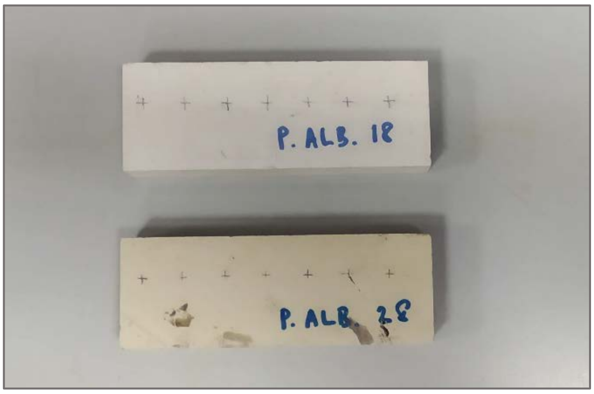

Figure 12: Thermal shock cycles affected the colouration of the specimens, revealing brownish yellow color. No fracturing or detachment were observed.

Figure 13: Visible staining as effect of temperature and moisture on the he specimen P ALB 20 in comparison with P ALB 18 in natural conditions.

3.3 Petrographic analyses

The scope of the analyses was to search for relevant fossils, to classify the limestones (whether they come from the Bari or Altamura Series) and to perform a Folk classification. The images collected are shown in Figures 14 and 15.

Figure 14: Image captured from the thin-section specimen from Palmisano Quarry.

In this thin section, a fragment of fossil shell can be observed (possibly from a bivalve) as well as foraminifera and algae rests. The bioclastic fraction appears to be very badly preserved, and it is difficult to assess the nature of the fossils. From the Folk classification (Folk, 1962), this limestone is a biomicrite, with 10 to 20% bioclasts.

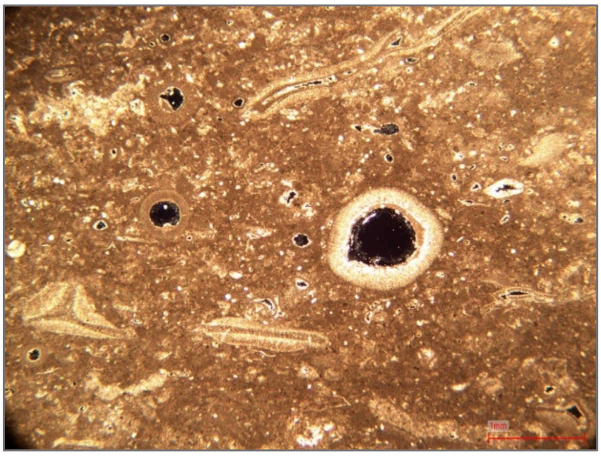

Figure 15: Microscopic observation of fossils in the thin-section specimen from Trullo Palmullo.

Trullo Palmullo exhibits a different population of fossils, seldom with a compressed shape. Alveolinidae and algae can be seen and the bioclast concentration is about 45 to 50%. Using the Folk classification method, this limestone is a biomicrite.

Microscopic observations did not allow the definition of the geological origin of the samples, since guide fossils such as Rudiste and Foraminifera (Checconi et al., 2008) could not be identified. The biological material was unrecognisable since it was highly fragmented and heavy re-crystallisation had occurred, making clear identification of biological remains very difficult. However, the numerosity and dimensions of the fossils and bioclasts could be quantified, to characterise how these properties may influence the mechanical response of the specimens (Table 5).

Table 5: This table summarises the results of flexural strength of the samples and relates them to the quantity and average dimensions of the fossils found by microscopic observation.

<table>
<tr><th>GROUP</th><th>R_{tf} (MPa)</th><th>Fossil percentage</th><th>Fossil average dimensions (mm)</th><th>Fossil maximum dimensions (mm)</th></tr>
<tr><td>P. ALB. Natural conditions</td><td>11.4±4.2</td><td rowspan="2">10 to 20%</td><td rowspan="2">0.13</td><td rowspan="2">2.0</td></tr>
<tr><td>P. ALB after artificial ageing</td><td>13.7 ± 1.2</td></tr>
<tr><td>Trullo Palmullo (mean between A and B)</td><td>15.4±4.0</td><td>45 to 50%</td><td>0.12</td><td>2.3</td></tr>
</table>

The fossils content percentage reflect a difference in the depositional environment while the mechanical resistance of the two stones are similar mainly after the artificial ageing of the quarry sample.

3.4 Distribution of mechanical properties inside the chiancarella

Through the observations conducted on the reconstructed stone, it is possible to define four distinct areas in which the mechanical properties are distributed (Table 6). Those coloured in light grey, which represent the best performing areas, belong to the upper face of the stone: the specimens TPI A 1, 2 and 3 belong to the weathered part of the stone, while 4, 5 and 6 belong to the unaltered part. The specimens from the bottom face of the stone show mechanical parameters generally below average, which may be due to the shape of these samples; they are thinner, and the cut of their geometry is not as precise as that of samples from the upper face. Again, considering the bottom layer (see Figure 11), specimens from the un-weathered half of the stone have better mechanical properties (samples TPI A 10, 11 and 12) than those from the weathered half (TPI A 7, 8 and 9).

Table 6: UPV and flexural strength results for different areas of the chiancarella from Trullo Palmullo.

ID	UPV (m/s)	Mean UPV (m/s)	R_{tf} (MPa)	Mean R_{tf} (MPa)
TPI A 1	2071		15.7	
TPI A 2	2108	2080	15.1	15.0
TPI A 3	2053		14.2	
TPI A 4	2365		19.0	
TPI A 5	2349	2340	19.2	19.3
TPI A 6	2310		19.6	
TPI A 7	2105		10.6	
TPI A 8	1777	1935	8.6	10.6
TPI A 9	1923		12.5	
TPI A 10	1867		15.5	
TPI A 11	1907	1920	15.5	15.5
TPI A 12	1977		15.4	

3. 5 Correlation of physical and mechanical properties

It was possible, for the sample from Trullo Palmullo, to recognise correlation trends between the physical and mechanical properties of the medium, particularly between UPV and R_{tf} and between UPV and WA (Figures 16 and 17). UPV measure is especially useful for this study, as it can be determined on-site through non-invasive testing. The correlation between UPV and R_{tf} shows a clearly growing trend, meaning that a stiffer material (one with higher pulse velocity) from this stone sample will likely show a higher resistance to flexion. Sample TPI A 7 was considered to be an outlier, since part of it was too slender to perform correctly during the test.

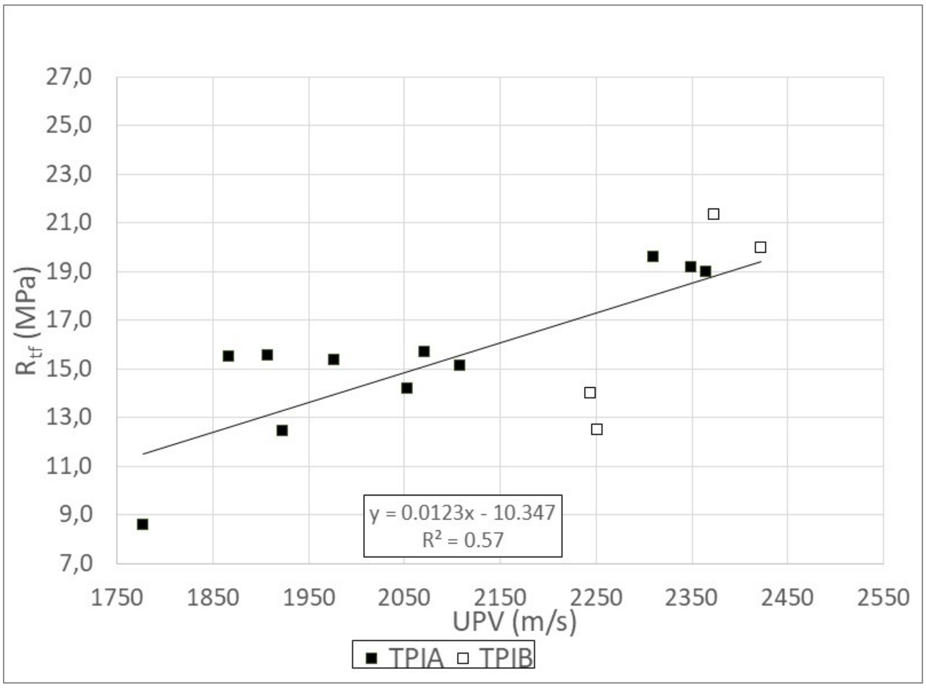

Figure 16: Increased UPV values are correlated with increased flexural strength of the specimen. Specimens TPI A 7 and TPI B 1 were considered to be outliers.

Comparing the performances of specimens in the UPV and WA tests, the correlation shows a clearly decreasing trend. This is reasonable, since stiffer material is likely to be less porous and less prone to absorbing water. Again, sample TPI A 7 was considered an outlier.

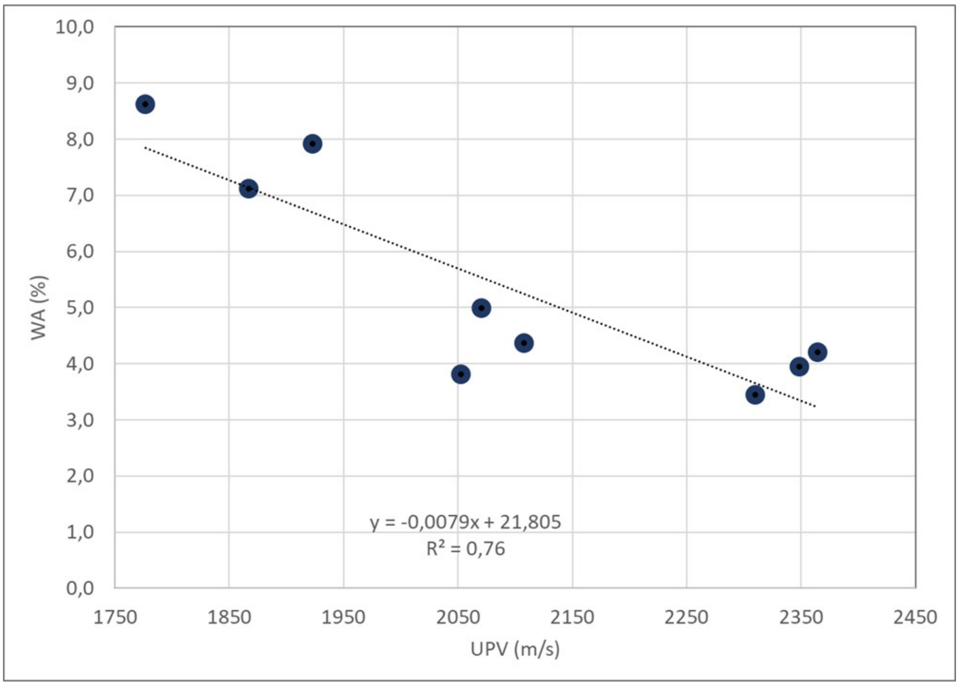

Figure 17: The correlation between ultrasonic velocity and water absorption inside TPI A samples.

4. Conclusions

The aim of this research was to characterise the natural stone coming from Itria Valley, as it represents an essential component in the cultural heritage of the region; a deeper knowledge of this is key for the correct implementation of restoration actions and for the choice of the most adequate materials to be used.

Several sources of material were tested and analysed, both on-site and in the laboratory, and the observations on them have been promising:

- The correlation trends show how different physical-mechanical properties can be linked, to extrapolate information about the material, even from on-site tests, e.g. UPV measurements.
- The ‘reconstruction’ of the chiancarella from Trullo Palmullo allowed us to assess how the technological properties of these materials vary, even inside a single stone, depending on the state of weathering, and the position and shape of the sample inside the whole stone.
- Accelerated ageing, both with thermal shock and thermal/moisture cycles, did not affect the specimens as expected, possibly because of the resistance of the material to weathering. However further studies could be done with more ageing procedures in order to better demonstrate this.

This information, can be a useful instrument for the architect and expert in restoration work as the “new” stones of Itria Valley show a mechanical strength similar to historical “chiancarelle” employed in the “trulli” heritage constructions and therefore they are useful for substitution of the ancient ones where needed.

The observations, analyses and conclusions produced in this work can be the basis for further research to promote the cultural heritage of Itria Valley and its natural stone. The results of this laboratory analysis could be a reference for the next publication of ‘Natural Stone and Cultural Heritage’, focussing on Itria Valley.

Author Contribution Statement

Conceptualisation: Bellopede, Merico, Marini; Data curation: Merico; Investigation: Bellopede, Merico, Marini; Methodology: Bellopede, Merico; Supervision: Bellopede, Marini, Fiorucci; Validation: Bellopede, Marini; Writing-original draft: Bellopede, Merico, Marini; Writing-review and editing: Bellopede, Merico, Marini, Fiorucci.

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