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Use of By-Products of Luserna Stone for Construction Materials: Sustainability and Economic Feasibility

Gabriele Vola[1], Enrico Lovera[1], Roberto Tezza[2], and Edoardo Piazza[3]

[1]*CTG Italcementi Group, via Camozzi 124, 24121, Bergamo, Italy.*
[2]*Calcestruzzi Spa, Via Baden Powell, 2, 10024, Moncalieri (Torino), Italy.*
[3]*Studio Test, Via Aldo Moro 38, 24050, Zanica (Bergamo), Italy.*
E-mails: <g.vola@itcgr.net>, <e.lovera@itcgr.net>, <r.tezza@calcestruzzi.it>, <piazza@studiotest.it>.

ABSTRACT

The paper deals with the state-of-the-art of the know-how related to the re-use of by-products resulting from the quarry exploitation and processing of the “Luserna Stone” (Piedmont). The existing studies and researches done in the part are briefly reviewed, and the in-progress projects are described with details, focusing on the industrial perspectives in the short-medium terms. In particular the results of recent studies and tests done by Italcementi Group are discussed: these tests mainly deal with a technical-economic assessment for the re-use of stone by-products in the industrial production process of concrete. Recently some crushing tests have been done in an aggregate plant of Italcementi Group, processing 110 t of stone wastes extracted from the “social” dump area of Bagnolo Piemonte, Cuneo, Italy. Aggregates obtained after crushing have been screened according to the typical size classes and evaluated according to EN 12620 in order to evaluate the suitability for industrial applications.

INTRODUCTION

The role of mineral commodities is clearly relevant for economic and social progress of communities, but on the other hand the impact on environment, natural resources’ depletion and cultural asset may be negatively relevant too.

In particular the European aggregate industry (extraction, processing and transport), being the main provider of materials for the construction sector (infrastructures and buildings), has a strategic importance to guarantee the economic growth, but as a consequence of the large quantities involved (approx. 3 billion tons per year, from more than 30,000 quarries across Europe), the environmental impacts are not negligible.

European Countries have been managing the issue since the 70’s through different “administrative” tools: e.g. the mining permit, granted after the approval of a mining project; the development of planning policies; the application of taxes and royalties to be used for environmental compensatory works; the environmental impact assessment for large scale mining projects, etc…

Focusing on the Italian situation, the main target of mineral policies, even if different on regional basis, has been two-fold: 1) ex ante minimisation of impacts, working on the design phase of the quarries and on the planning of the sector; 2) contextual or ex post compensation through environmental restoration.

So far, the managing of the extractive sector in Italy has not been primarily aimed at reducing the quantity extracted or at promoting alternative materials, but mainly at balancing the externalities associated with quarrying activities through investments implemented by both Companies and by the public institutions that share the revenues of taxes and royalties. Practically the strategy has been to allow extraction to grow according to market demand, trying to control and minimise the impact on land resources. This approach may be defined as “weak sustainability”, according to which the reduction in natural capital due to quarrying (mineral deposit) is compensated by investments in natural capital in the same site at the end of operations or in the surrounding areas (environmental restoration), and investment is internalised in quarrying production costs through the charges levied.

Just in the last years the attention has been more clearly concentrated on the resource scarcity and on the “competition” with other uses of resources (e.g. water protection), and accordingly policies aimed at the reduction of demand of “primary” aggregates and at encouraging the use of “alternative” sources for aggregates will be more and more promoted by the different regulatory levels (from EU to local levels).

So far Italy has recorded a very small “recycling” rate (approx 1%, expressed as percentage of total input of aggregates, UEPG, 2008), which is probably due to relatively abundance of mineable deposits throughout the country (approx. 1800 companies are operating on 2500 sites, UEPG, 2008), a strong market preference for “primary” aggregates and the lack of significant price difference between virgin and alternative materials. However, the growing pressure on both producers and consumers is likely to force the sector towards the progressive reduction of consumption of primary aggregates by switching to recycled or secondary aggregates.

Secondary aggregates are normally defined as by-products of other industrial processes, such as the quarrying of dimension stones, which typically involves the production of an high percentage of lithoid waste (in some cases > 70% of the excavated volume). The re-use of these products is particularly interesting for construction application because of the availability on the territory, and the physical-mechanical characteristics. Of course the latter point is critical whenever the suitability of the material for the final use is defined by precise international standard, as for aggregate for concrete. The following chapters are dealing in particular with this important topic.

Another critical aspect to be considered is that, in the Italian context, aggregate materials are typically low-cost bulky products, and as a consequence the economic supply radius is limited to 35-50 kilometres (depending on local road network and diesel prices). The business is highly transport-sensitive (on the average transport is around 13 % of total costs), and it is very difficult to act on this factor, unless special local conditions are possible, e.g. synergies with rail transportation. Some considerations on this topic are presented in the conclusions.

Italcementi Group, the Italian leader for cement production and among the first cement producers in the world, is strongly committed in sustainable development policies, and one field of research performed by his Technical Center of the Group (C.T.G.) is devoted to the substitution of raw materials needed in the different phases of the process. For concrete production, another important business of the Group, operated by the subsidiary Calcestruzzi Spa, the retrieval of alternative materials with suitable technical characteristics to be used as aggregates is of course strategic in order to proceed towards sustainable constructions.

The following chapters deal with the recent research done in the Luserna-Infernotto quarrying basin, located in Piedmont Region, selected as potential target because of the following main reasons: availability of approx. 70,000 m^3/year of material mined but not used for dimension stone processing or other uses [D'Amato et al., 2005], and normally destined to dumps; material already dumped in the past estimated in 4,000,000 m^3 [Fornaro, 2003]; relative proximity to an important market for aggregates, such as Torino municipality and the infrastructure network of Padana Valley; the presence of aggregate processing plants of Calcestruzzi S.p.a. to perform industrial tests in the surroundings of Torino; the scientific base of previous researches and studies performed mainly by the Politecnico and University of Torino (see the works of [Sandrone et al., 1989 and Fornaro et al., 1991], for early references on the possibilities of reduction of waste production and the re-use first hypothesis; [Sassone et al., 1995], about researches on possibilities to recover industrial minerals from special processing of wastes; [D'Amato et al., 2005 and Dino et al., 2005], about recent and innovative experiences).

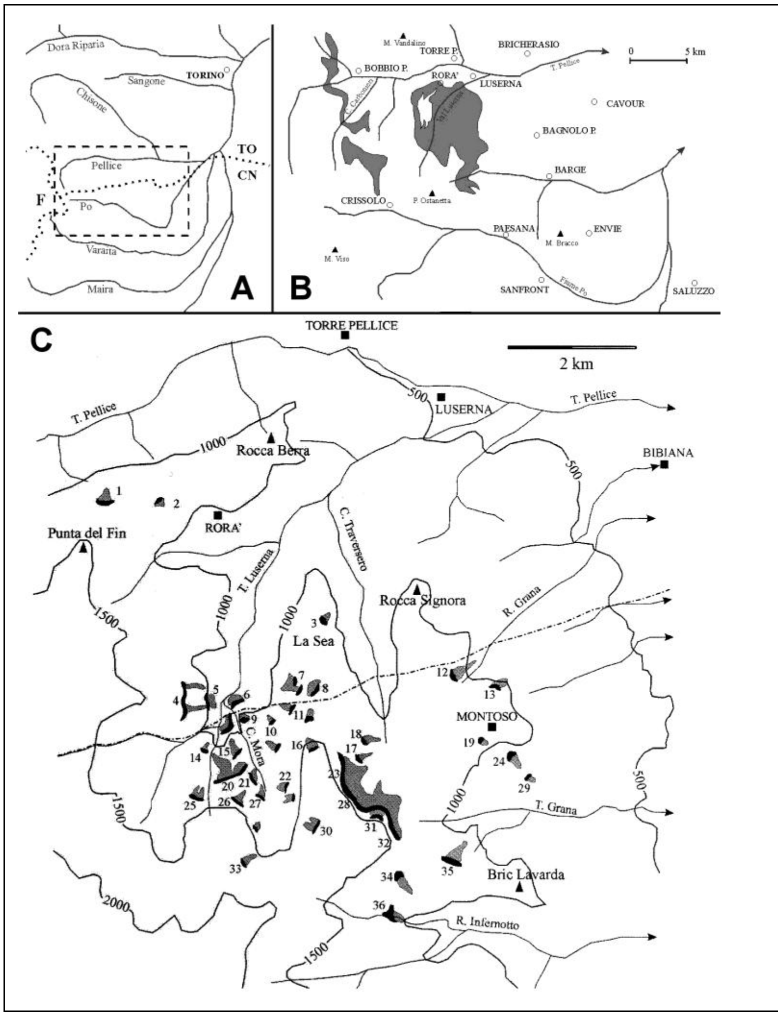
From a legislative viewpoint, the fluent quarry "waste" is properly considerable as a raw material waiting for further processing. Materials unsuitable for dimension stone processing are already commonly used for hydro-geological stabilization (blocks for river embankments and retaining walls), while finer material is used as an aggregate for road sub-bases and as railway ballast [Sandrone et al., 2000; Lovera et al., 2001; Fornaro et al., 2003; Sandrone et al., 2004]. An example of an important re-use of such materials was experienced to provide aggregates for the civil works done for the Winter Olympic Games held in Torino in 2006 (435,000 m^3, D'Amato et al., 2005), and for the construction of the highway Torino-Pinerolo (250,000 m^3, D'Amato et al., 2005).

THE LUSERNA STONE

Luserna Stone (Pietra di Luserna) is a leucogranitic orthogneiss, probably from the Lower Permian Age, that outcrops in the Luserna-Infernotto basin (Cottian Alps, Piedmont) on the border between the Turin and Cuneo provinces. Characterized by a micro "Augen" texture, it is grey-greenish or locally pale blue in color. Luserna Stone quarrying and processing activities have been very significant for the Italian natural stones business since the end of the 19^{th} century, and in the last years the amounts quarried every year total approx. 390,000 m^3/year from approx. 60 quarrying sites. Geologically, Luserna Stone pertains to the Dora-Maira Massif [cf. review in Sandrone et al., 1993] that represents a part of the ancient European margin annexed to the Cottian Alps during the Alpine orogenesis. From a petrographic point of view, it is the metamorphic result of a late-Ercinian leucogranitic rock transformation [Compagnoni et al., 1982-83]. The Luserna Stone has a sub-horizontal attitude, with a marked fine-grained foliation that is mostly associated with visible lineation. The mineralogical composition includes K-feldspar (10-25 Wt. %), quartz (30-40 Wt. %), albite (15-25 Wt. %) and phengite (10-20 Wt. %); subordinated biotite, chlorite, zoisite and/or clinozoisite/epidote (less then 5%). In addition to common accessory phases (opaque minerals, titanite, apatite and zircon), tourmaline, carbonates, rare axinite and frequent fluorite are present [Sandrone et. al., 2001]. Lithological features and building applications allow recognizing two varieties of Luserna Stone: 1) micro-augen gneiss with very thin deformed feldspar eyes, regular schistosity planes with centimetric spacing and easy split workability, known as Splittable facies; 2) micro-Augen gneiss with not so elongated and closer feldspar eyes, characterized by lower schistosity and poor split, suitable for blocks cutting using diamond wire saws, known as Massive facies [Sandrone et al., 2001]. Finally, a quite rare white variety exists, called “Bianchetta” or “Zebrato”, composed of quartz, albite, phengite and very little microcline. The physical and mechanical properties of the Luserna Stone are excellent, showing very good compressive, flexural and impact strength and low water absorption [Regione Piemonte, 2000].

Table 1: Luserna Stone physical-mechanical characterization (Regione Piemonte, 2000)

Typology	Massive facies	Splittable facies
Mechanical strength (MPa)	128	-
Flexural strength (MPa)	21,3	24,3
Impact strength (J)	8,0	8,8
Knoop microhardness (MPa)	4269	4486
Water absorption (%)	0,29	0,31



A: Location of the Luserna Stone district in Piedmont area. The dotted line points out the border between Italy and France, while the cross-hatching line the border between Turin and Cuneo Provinces;

B: Location of the Luserna Stone outcrops (dark area);

C: detailed map of Luserna Stone district with quarries (active inactive, abandoned) and dumps location. Legend: 1: Bruard; 2: Loetta; 3: Bordella; 4: Inverso Cornour, Barma, Baracca Bianca, Butin-Rocca Mourò, Rocca del Bec, Rocche Alte 1, Rocche Alte Sud, Bonetto del Prete, Bonettone, Noughet, Gran Rocca Nord, Gran Rocche-Barmatai, Ciabot; 5: Salé, Spinafoglio, Prà del Torno; 6: Seccarezze; 7: Ambrasse; 8: Sea, Sea Bassa; 9: Lestu; 10: Mugniva; 11: Casassa; 12: Pian Furnas; 13: Montoso; 14: Galiverga; 15: Tube; 16: Ruccas; 17: Crivella Inferiore; 18: Conformo; 19: Montoso Sud; 20: Ciafalco; 21: Avei; 22: Barmass, Barmass Basso; 23: Crivella Superiore; 24: Fontanette; 25: Bolla; 26: Pret; 27: Acqua Saporita; 28: Bricco Volti; 29: Madonna della Neve; 30: Barmassa; 31: Ortiolo, Rocche Grana; 32: Casette; 33: Cuvertà; 34: Cassetta; 35: Pravallino; 36: Balma Oro. Barmassa and Cuvertà quarries doesn’t extract the typical Luserna Stone, but a very laminated variety of micro-augen gneiss, namely “Bianchetta” or “Zebrato”.

Fig. 1: Location of Luserna Stone quarrying district [Sandrone and Alciati, 2001]

EXPERIMENTAL INVESTIGATION PLAN

CTG preliminary study of the Luserna-Infernotto basin started in 2006. The first step was to identify and characterize different typologies of Stone, i.e. Massive and Splittable facies; the second one was to evaluate quantity and quality of by-products collected into the social dumps. A master degree in collaboration with the Politecnico di Torino (Prof. R. Sandrone and Dr. Marini) has been carried out in 2007, with the aim of preliminary assessing the re-use stone by-products in the production of aggregates for concrete (see Vola et al. 2008 for results).

The second step of this study was performed in 2008 with the operative support of Calcestruzzi Spa, when 110 tons of Luserna Stone by-products were taken from the "Galiverga" dump in Bagnolo Piemonte, in-pit crushed (30-40 mm size), and finally transported to the "Cava Monviso" plant in Casalgrasso (40 km distant from quarries) for industrial crushing and classification in commercial size classes (Figure 2).

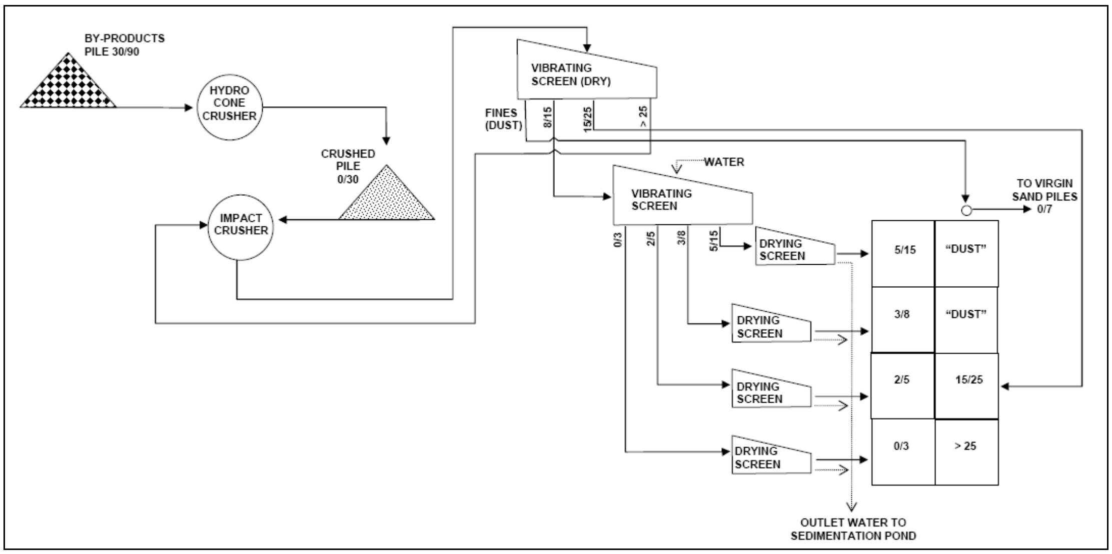


Fig. 2: Flow sheet of the crushing and screening plant used for the industrial test at "Cava Monviso", Casalgrasso, Cuneo.

The site where the material has been taken from was chosen after the evaluation of logistic road network's conditions until the processing site. Materials sampled during 2006-2007 researches, as well as aggregates obtained after industrial crushing tests in 2008 have been characterized according to the standard EN 12620/2008. Furthermore technological assays and test have been performed to asses the workability of the concrete mixtures specifically designed to use such aggregates (rheological and slump tests by means of the Concrete Equivalent Mortar – CEM – method; [Schwartzentruber and Catherine, 2000]). Analytical and technological tests have been done at the CTG Laboratories Department, whereas draft sheets for CE marking have been complied at the Studio Test lab.

AGGREGATES CHARACTERIZATION

Materials selection

The first sampling of Luserna Stone by-products was done in 2006 in the Galiverga social dump. 30-40 cm grain-sized material was taken for preliminary examinations. The second sampling was performed in 2007. Quarries of Seccarezze Pole for Massive facies and quarries of Bricco Volti Pole for Splittable facies, have been considered. Materials were crushed in the Politecnico lab by means of Magutt crusher and monogranular particle-size distribution curves (0/16 mm and 0/20 mm) have been obtained[1]. The last sampling in Galiverga dump and the industrial crushing test in the industrial plant of "Cava Monviso" were both carried out in 2008. The following fractions have been subsequently considered: 0/3 mm, 2/5 mm, 3/8 mm, 5/15 mm and 15/30 mm (Table 2).

Table 2: Luserna Stone samples (2006-2009)

Material	Year	Typology	Origin	Grain Size*
Luserna Stone	2006	Dump Mix	Galiverga dump	0/16 mm
Luserna Stone	2007	Massive	Seccarezze Pole	0/20 mm
Luserna Stone	2007	Splittable	Bricco Volti Pole	0/16 mm
Luserna Stone	2008	Dump Mix	Galiverga dump	0/3 mm
Luserna Stone	2008	Dump Mix	Galiverga dump	2/5 mm
Luserna Stone	2008	Dump Mix	Galiverga dump	3/8 mm
Luserna Stone	2008	Dump Mix	Galiverga dump	5/15 mm
Luserna Stone	2008	Dump Mix	Galiverga dump	15/30 mm

Legend: * = after the crushing test

Materials macroscopically description

Crushed aggregates from Seccarezze pole, which is the source of Massive Stone variety, showed very low schistosity, due to the small amount of laminated minerals (phyllosilicates) (see Figure 3A). Crushed aggregates from Bricco Volti pole, which production is mainly of Splittable Stone variety, showed a typical schistose texture, due to the high amount of phyllosilicates (see Figure 3B). Luserna Stone phyllosilicates mainly consist of a pale green mica, namely phengite, with subordinated amounts of chlorite and biotite. With regards to crushed aggregates from Galiverga dump, they consist of by-products coming from both poles, so they are composed by a mixture of Massive and Splittable Stone varieties.

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[1] To be recalled that the particle-size distribution curves obtained by means of the Magutt crusher are monogranular distributions, quite different from those normally adopted to design concrete mix, as far as the lack of fines, which are suitable for plastic-fluid slump flow (S2-S3). Grain-size distributions designed for concrete production are generally produced mixing specific quantities of almost three different fractions. With regards to Bolomey standard curves, it's possible to increase concrete workability, increasing the amount of fines and modifying the parameter depending on grains form (e.g. A-parameter is for crushed aggregates, while B-parameter for rounded aggregates) (Coppola, 2006).

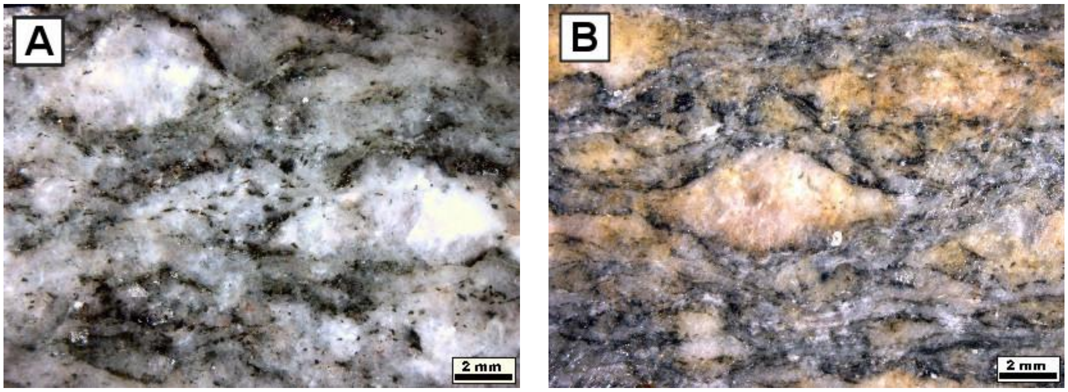

Fig. 3: Macrographs of Luserna Stone varieties: A: Massive facies; B: Splittable facies (samples before crushing test) (Vola et al., 2008).

Geometrical requirements (EN 12620)

The first requirement of the CE Standard is the aggregate description in terms of sizes using the designation d/D. The particle-size distribution curves (EN 933-1) of 2007-2008 samples are plotted in the figure 4. The fines content (EN 12620-Annex D), the fineness modulus (EN 12620-Annex B), the shape index (EN 933-4) and the flakiness index (EN 933-3) of 2007 samples are reported in the Table 3. With regards to 2008 samples only fines content and fineness modulus are reported.

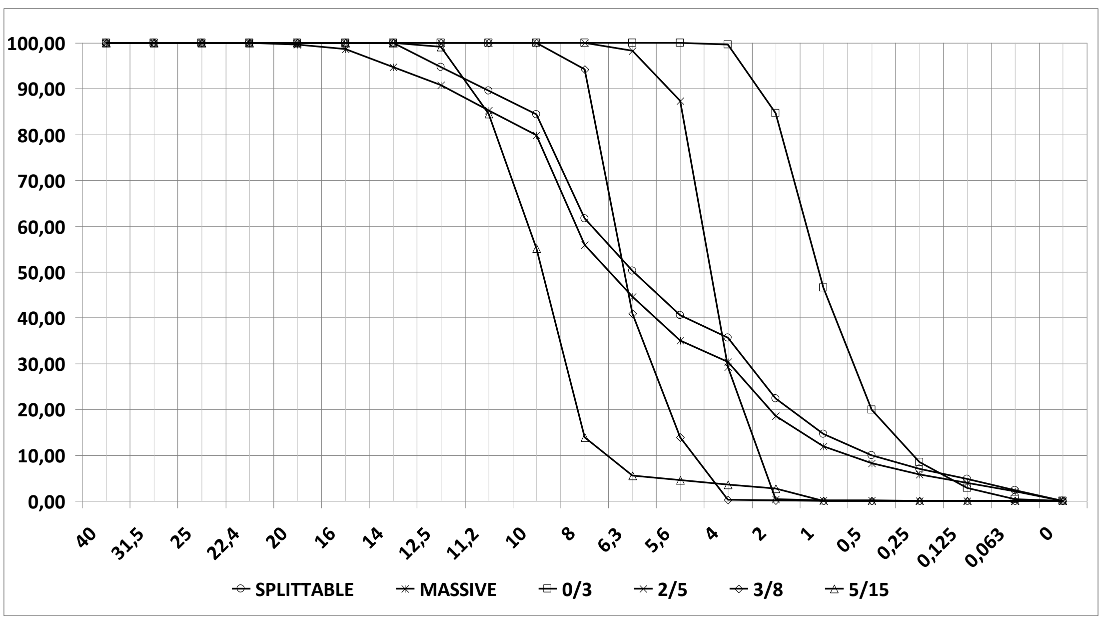

Fig. 4: Particle-size distribution curves of Luserna fractions

Table 3: Luserna aggregates geometrical properties (samples 2007-2008)

Sample	0/20	0/16	0/3	2/5	3/8	5/15	15/30	Category
Year	2007	2007	2008	2008	2008	2008	2008	-
Typology	Mass.	Split.	Mix	Mix	Mix	Mix	Mix	-
Fines* (%)	2,62	2,85	3,02	0,07	0,10	-	-	F_3
Fines**(%)	-	-	-	-	-	0,38	0,99	$F_{1,5}$
Fineness modulus (%)	0,96	0,95	3,57	5,12	6,05	7,04	7,60	-
Shape index (%)	20	22	-	-	-	-	-	SI_{40}
Flakiness index (%)	19	21	-	-	-	-	-	FI_{35}

Legend: * = fine aggregates; ** = coarse aggregates

Physical-mechanical requirements (EN 12620)

Physical-mechanical examinations on the first batch of samples (2006-2007) consist of the following determinations: resistance to fragmentation (Los Angeles Test: EN 1097-2), resistance to wear (micro-Deval test: EN 1097-1), real density by a gas picnometer, total porosity by the mercury intrusion porosimetry and BET/N_2 specific surface area. Results are reported in the Table 4.

Table 4: Luserna aggregates physical-mechanical properties (Vola et al., 2008)

Sample	0/20	0/16	Category
Year	2007	2007	-
Typology	Mass.	Split.	-
Los Angeles coefficient (%)	29	27	LA30
Micro-Deval coefficient (%)	10	7	M_{DE}10
Real density (kg/m³)	2,65	2,63	-
Total porosity (%)	1,2	1,3	-
BET/N2 Specific Surface Area (m²/g)	0,4	0,3	-

Physical-mechanical examinations on the second batch of samples (2008) were carried out at Studio Test lab: bulk density (EN 1097-3) and water absorption (EN 1097-6) were performed on all the grain-size fractions, while the resistance to fragmentation (Los Angeles Test) and the resistance to wear (micro-Deval test) were performed only on fractions 5/15 mm and 15/30 mm. Results are reported in table 5. LA and M_{DE} values are comparable with those of many commercial alluvial aggregates coming from Padana Valley, in spite of 2008 categories are one class higher then those detected on 2007 samples.

Table 5: Luserna aggregates physical-mechanical properties (2009 samples)

Sample	0/3	2/5	3/8	5/15	15/30	Category
Year	2008	2008	2008	2008	2008	-
Typology	Mix	Mix	Mix	Mix	Mix	-
Bulk density (Kg/m³)	2,65	2,68	2,67	2,67	2,65	-
Water absorption (%)	1,50	0,87	0,80	0,83	0,94	-
Los Angeles Coefficient (%)	-	-	-	32,5	33,86	LA35
Micro-Deval Coefficient (%)	-	-	-	11,3	10,6	M_{DE}15

Chemical requirements (EN 12620)

EN 12620 standard points out the necessity to define the origins and characteristics of materials from secondary sources. These materials when placed on the market as aggregates must comply fully with this standard and national regulations for dangerous substances, depending upon their intended use. Considering our general objective, the chemical analysis by means of X-Rays Fluorescence spectroscopy (XRF) was detected on 2006-2008 samples. Results reported in the table 6 show the constancy in composition and the absence of harmful constituents.

Table 6: Luserna aggregates chemical composition (2006-2008 samples)

Samples	0/16	0/20	0/16	0/3	2/5	3/8	5/15	15/30
Year	2006	2007	2007	2008	2008	2008	2008	2008
Typology	Mix	Mass.	Split.	Mix	Mix	Mix	Mix	Mix
SiO_2	77,84	75,62	77,55	78,33	78,18	77,57	77,28	74,93
Al_2O_3	11,44	12,56	11,2	11,31	11,33	11,63	11,66	13,03
Fe_2O_3	1,08	1,56	1,36	1,09	1,08	1,08	1,21	1,3
CaO	0,31	0,69	1,12	0,2	0,25	0,25	0,34	0,43
MgO	0,12	0,22	0,09	0,37	0,2	0,2	0,38	0,28
SO_3	0,2	0,08	0,08	0,07	0,07	0,08	0,07	0,15
Na_2O	3,55	2,87	3,02	2,91	3,18	3,47	3,26	3,72
K_2O	4,21	5,03	4,86	4,68	4,82	4,81	4,69	4,96
SrO	0,04	< 0,03	< 0,03	0	0	0	0	0
Mn_2O_3	< 0,04	0,05	< 0,04	0,05	0,05	0,05	0,05	0,05
P_2O_5	< 0,03	0,19	0,1	0,04	0,03	0,04	0,04	0,04
TiO_2	0,14	0,14	0,11	0,03	0,06	0,04	0,08	0,08
Loi	0,71	0,76	0,33	0,78	0,60	0,62	0,80	0,89

Mineralogical-petrographic characterization and phyllosilicates amount

As far as the formation of flaky grains during crushing tests, the problem is related to the natural schistosity of Luserna Stone by-products: this is the reason why a deepen mineralogical-petrographic characterization was required. Therefore the mineralogical composition was investigated by means of X-Ray powder Diffraction analysis (XRD) and the petrographic examination on thin sections was carried out on 2006-2008 samples. Especially the Quantitative Phase Analysis (QPA-XRD) was performed using the Rietveld method [Rietveld, 1969; Young, 1993]. Crystal structures were selected from the literature and structural refinements on XRD patterns were carried out using GSAS-EXPGUI software package [Larson and Von Dreele, 2000; Toby, 2001]. The reliability of this method has been verified by Vola and Marchi (2009). This kind of approach permits one to detected the total amount of phyllosilicates (phengite, chlorite and biotite) which could be critical for concrete workability, in terms of slump flow reduction, and also for the potentially reduction of mechanical strength in the hardened concrete [Wakizaka et al., 2005]. Results show that quartz and feldspars are the main phases, while phengites (2M1 and 3T polytypes were both detected, see Vola and Marchi, 2009), biotite, clinochlore, clinozoisite, titanite and Lizardite are all subordinated phases. Phengite could be considered main phase just in the case of 2007 sample (Splittable facies). The presence of Lizardite inside the samples is considered a contamination occurred during the crushing test. The mean of phyllosilicates is approx. 9.2%, which is not a critical factor in terms of rheological behaviour for mortar workability (see the technological tests in the next chapter).

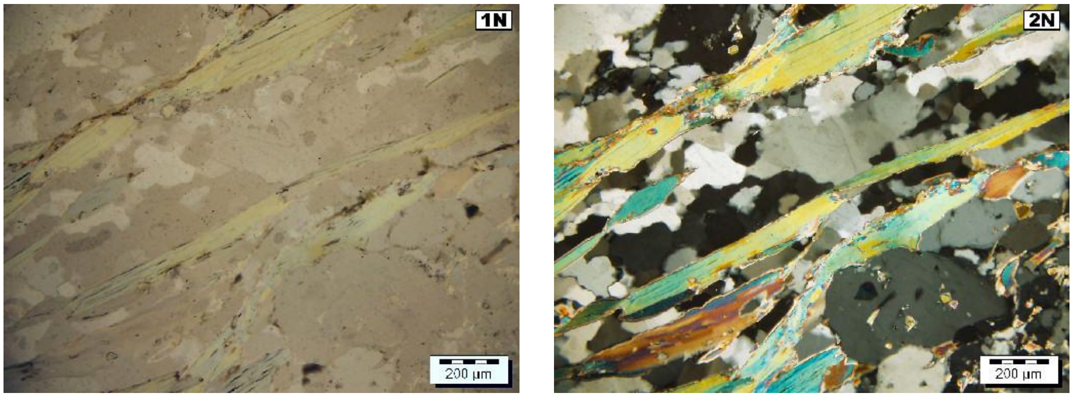

Fig. 5: Micrographs on thin section (10x) show the mineralogical layering of phengites in the Splittable facies. Legend: 1N=parallel nicols, 2N=crossed nicols.

Table 7: Luserna aggregates mineralogical composition (2006-2008 samples).

Sample	Year	Typology	Origin	Main Phases	Subordinate Phases
0/16	2006	Dump Mix	Galiverga	Qtz + Ab + Mc	Phg + Clc + Czo + Tnt
0/20	2007	Massive	Seccarezze	Qtz + Ab + Mc	Phg + Clc +Bt + Czo
0/16	2007	Splittable	Bricco Volti	Qtz + Ab + Mc + Phg	Clc + Bt
0/3	2008	Dump Mix	Galiverga	Qtz + Ab + Mc	Phg + Bt
2/5	2008	Dump Mix	Galiverga	Qtz + Ab + Mc	Phg + Bt
3/8	2008	Dump Mix	Galiverga	Qtz + Ab + Mc	Phg + Bt
5/15	2008	Dump Mix	Galiverga	Qtz + Ab + Mc	Phg + Bt + Lz
15/30	2008	Dump Mix	Galiverga	Qtz + Ab + Mc	Phg + Bt + Czo

Legend: list of mineral abbreviations from Siivola and Schmid (2007).

Table 8: Structural models

Phase name	Abbreviation	Code	References
Quartz	Qtz	79634-ICSD	Glinnemann et al. (1992)
Albite low	Ab	26248-ICSD	Ribbe et al. (1969)
Microcline int.	Mc	9542-ICSD	Bailey (1969)
Phengite 2M1	Phg 2M1	87844-ICSD	Pavese et al. (1999)
Phengite 3T	Phg 3T	1100016 data	Pavese et al. (1997)
Clinochlore	Clc	84262-ICSD	Smyth et al. (1997)
Biotite	Bt	9002301 data	Brigatti et al. (2000)
Clinozoisite	Czo	9001799 data	Comodi & Zanazzi (1997)
Titanite	Tnt	9000509 data	Taylor & Brown (1976)
Lizardite	Lz	9007424 data	Auzende et al. (2006)

Table 9: Quantitative Phase Analysis by the Rietveld method (XRD-QPA)

Samples	0/16	0/20	0/16	0/3	2/5	3/8	5/15	15/30
Year	2006	2007	2007	2008	2008	2008	2008	2008
Typology	Mix	Mas.	Split.	Mix	Mix	Mix	Mix	Mix
Qtz	45,4	41,9	45,5	41,2	42,3	39,8	38,1	36,5
Ab	33,5	25,5	27,3	25,4	27,6	28,2	31,2	31,2
Mc	15,1	22,8	15,3	21,9	22,1	23,3	21,6	21,9
Phg 2M1	4,3	5,3	7,6	4,3	3,5	4,9	3,6	4,4
Phg 3T	0	0	0	3,4	1,8	1,8	2,2	0,9
Clc	0,9	2,6	1,7	0	0	0	0	0
Bt	0	0,8	2,6	3,9	2,8	2,0	3,2	3,8
Lz	0	0	0	0	0	0	0,2	0
Czo	0,8	1,1	0	0	0	0	0	1,3
Tnt	0,7	0	0	0	0	0	0	0
Feldspars	48,6	48,3	42,6	47,3	49,7	51,4	52,8	53,1
Phyllosilicates	**6,2**	**8,6**	**11,9**	**11,5**	**8,0**	**8,8**	**9,1**	**9,1**
Total	100	100	100	100	100	100	100	100

Potentially alkali-reactive quartz

Metamorphic quartz with undulatory extinction is considered potentially Alkali-Silica Reactive phase [Dolar-Mantuani, 1983]. The Italian standard UNI 8520-22 (recently under revision) also consider reactive the “crystalline quartz in alteration or tensional state with undulatory extinction angle higher then 15° or containing inclusions of micas, oxides or metallic sulphurs”. Because the amount of metamorphic quartz in the Luserna Stone is approx. 43%, in spite of no measurements of the undulatory extinction angle have been performed, EN 12620 standard requires for such aggregates the ASR investigation. Therefore a detailed plan of expansion mortar tests has been scheduled. The preliminary analysis on 2007 samples, according to the mortar microbar test (AFNOR P18-588/1991), gave a negative response (aggregates are not reactive). New tests on 2008 samples are going to be preformed at the University of Milan (Dept. of Mineralogy and Petrography) according to the ultra accelerated mortar-bar expansion test (Rilem AAR-2).

TECHNOLOGICAL TESTS

The test on properties of fresh mortar mixtures were conducted according to an internal CTG protocol defined in 2008 and nowadays in progress of optimisation. The slump tests were performed in 2009 using the concrete equivalent mortar method. Results are presented in Figure 6.

Rheological tests on mortar

For rheological test a rotational rheometer has been used. Such apparatus allows to measure, as a function of a fixed rotational speed (rpm) of the cup containing the mortar, the torque (N·mm) acting on a paddle, with a specific geometry, dipped inside the mortar. Thanks to the measurement system that can be approximated to a coaxial cylinders rheometer, from the measurement of the torque and of the rotational speed, it is possible to determine the Shear Stress (Pa) parameter and the Shear Rate (s^{-1}) by using defined mathematical equations function of the geometry of the apparatus. The result of the 15 minutes test is plotted in

Figure 6. The following mix-design has been adopted: water/cement ratio = 0.4; aggregate/cement ratio = 1.5; additive = 1% (on cement) of PCP acrylic super-plasticizer, cement type I 42.5 R in conformity with EN 197-1 standard. After milling and sieving fractions 0/2 mm, the following aggregates have been used in the mix (in brackets the phyllosilicates by the Rietveld method): Baveno pink granite (5%); Luserna Massive facies (8.6%); silica-calcareous alluvial aggregate from the Olona river (10%); Serizzo Formazza gneiss (12%); Luserna Splittable facies (12%).

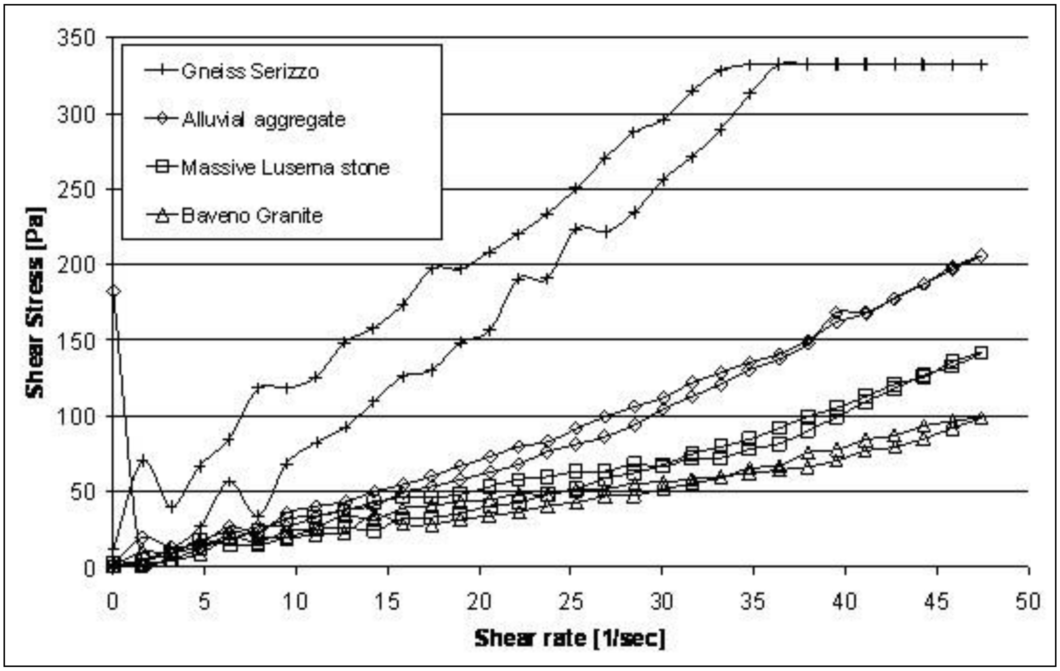

Fig. 6: Rheological curves of mixes with different aggregates.

The plot shows the strong influence of phyllosilicates on rheological behaviour, especially when the amount is over 12%. In the case of Luserna Splittable facies, the test showed a dramatic deterioration of the mix workability, so that it is not possible to measure it by the rotational rheometer.

Mortar slump test and PCP-phyllosilicates interaction

Recently some slump tests have been done in order to evaluate cement pastes workability using aggregates with different amounts of phyllosilicates, and so also Luserna aggregates have been considered. The following methodology was adopted: fines of the reference CTG sand (4.0%) were replaced by fines from aggregates containing different amount of phyllosilicates (Luserna, Serizzo, Baveno and Montorfano aggregates), then the behaviour of replaced sands has been studied in terms of concrete equivalent mortar (CEM) workability tests [Schwartzentruber and Catherine; 2000]. The following mix-design has been adopted: water/cement ratio = 0.44; aggregate/cement ratio = 2.0; additive = 1% (on cement) of acrylic PCP super-plasticizers, cement type II/B-LL 32,5 R in conformity with EN 197-1 standard. Results show that slumps of the replaced mortars are similar to that one used as reference mortar, moreover the PCP adsorption is very little.

RESULTS AND DISCUSSIONS

Preliminary results

Physical-mechanical properties of Luserna aggregates are generally good, even considering that the schistosity – especially for the Splittable facies – produces elongated grains during crushing. Experimental data after crushing test show that the two typologies of Luserna Stone do not present relevant differences of shape indexes, flakiness indexes, Los Angeles and micro-Deval coefficients. Specific surface area and total porosity of both typologies of Stone are very little, and anyway fines are inside the range established by EN 12620 standard. As far as chemical composition is concerned, no critical elements are detected, whereas the mineralogical and petrographic analyses have identified and measured the amount of the potentially harmful mineral phases for concrete: 1) laminated minerals, responsible for schistosity, i.e. phyllosilicates (Phg+Bt+Chl = 9.2%); 2) metamorphic quartz with undulatory extinction, potentially-ASR phase. On the one hand, rheological tests with mortar demonstrated that phyllosilicates in aggregates are critical on cement paste workability only in the case that their amount is over 12% (e.g. Serizzo aggregate and Luserna Splittable facies aggregate). On the other hand mortar microbar tests on Luserna aggregates gave negative response about ASR (aggregates are not reactive). In conclusion, the technical investigation on Luserna Stone by-products is giving positive results for the re-use as aggregates for concrete.

CONCLUSIONS

The reasons for supporting a research aimed at the re-use of natural stone by-product as aggregates for concrete are inscribed into the context of the so called Sustainable Resources Management policies.

The following points have been considered to justify such research:

- the total utilization of a natural non-renewable resource, such as stone, once it is exploited from the natural deposit, should be a target for both private companies and public administrations in order to improve the eco-efficiency of the quarrying and related sectors; accordingly a properly managed and systematic re-use of stone by-products should be definitely supported;
- natural resource consumption should be more and more reduced according to the principle of decoupling social-economical development and natural resource depletion. Again actions aimed at reducing the pressure on virgin resources has to be encouraged;
- the cost of natural aggregates will more and more include the externalities of the quarrying-processing-transport system. A more correct comparison between the production cost of a an aggregate quarry and the cost of the re-use of stone by-product should include all the environmental costs and benefits of the two options. This topic is still very critical for a practical application.

Of course, as stated before, in order to reach an industrial feasibility of the operation, some important conditions should be verified: first of all the “convergence” of interest between the producer of the by-product and the producer of aggregates-concrete. In the case of the Luserna Stone basin, for example, the position of the local quarry-owner representative and Calcestruzzi SpA did not find a convinced agreement so far, and the recent economical crisis has not sustained the operation.

At the moment, the logistic aspect remains extremely critical. To reduce the transport distance of the by-product, it would be strategic to locate a complete processing plant as closer as possible to the different quarries, and the site should be well connected to road network. The impact on local traffic should be evaluated, and if needed, proper interventions have to be planned involving private and public sector.

More favourable market conditions could be created by public administrations, e.g. by including in the specifications for public works that a part of aggregates have to come from non-virgin materials. For example, in a similar field, the United Kingdom used a proportion of the tax revenue from quarrying activities to develop specific quality standards for recycled aggregates which gave companies confidence in purchasing and using these materials. This was reinforced through awareness-raising campaigns to encourage local authorities to purchase recycled materials when carrying out local infrastructure projects (recycling rate is approx 25% in UK).

Finally, the fitness to purpose of the aggregates is of key importance for concrete applications, and product certification and marking is of course requested to enter the market. The research done by C.T.G. on the Luserna Stone is giving encouraging results for an industrial use as aggregates for concrete. The technical characteristics of the materials are fitting to the specification of international norms, and accordingly the Company will move forward on this way, looking for more favourable market conditions and sustainable synergies.

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