ENVIRONMENTAL IMPACT MINIMIZATION TECHNIQUE BY REUSE OF MINE WASTE AND TAILINGS

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ABSTRACT

Opening a new mine or a new quarry is subjected, in Italy, to some law-rules concerning recovery and restoration of the exploited area.

It is successful to plan the land restoration at the same rate as mining works. The restored area has to become an inset of the landscape.

A procedure is set up to allow to efficient land recovery of the mined area. It has been applied to an open-pit as results from the exploitation of a sand-ore deposit near Priverno in the south-west of the Latio - region in Italy.

The alluvial sand deposit, quite overlying and mainly constituted by feldspar and quartz free particles, dates back to the Pleistocen age and it is super imposed to a carbonaceous bed of the upper Cretaceous.

For land restoration two problems had to be taken into consideration:

- *high permeability of the sand layers as a consequence of the particle size distribution, with low water retention capacity of the over-burden;*
- *low stability of the landscapes as they remain after mine works.*

Geotechnical and agronomical characteristics of the land are, therefore, taken into consideration in order to assure the existence of the actual ecosystem and to extend the same environmental characteristics to the mined lands. Three kind of materials are taken into consideration:

- *the upper layer of the deposit and the over-burden;*
- *sandy-clay lens in to the sandy deposit;*
- *rejects of selective exploitation and tailings coming from the processing plant.*

Under a certain constraints it has been pointed out a blend of the refused materials which has been found optimal for land restoring and reclamation.

This work points out the research procedures, the geotechnical and agronomical tests and the main results.

INTRODUCTION

The need for stewardship and preservation of the environment increasing restraints on mining activity, both under ground and open pit mining. Enacting the several EEC directives, Italian legislation (Di Majo, 1993; Maglia and Santoloci, 1996; Lazio Region, 1993) entails the application of ever stricter regulations in both the exploitation and restoration phases of mining.

In particular, Italian legislation requires that from the start of exploitation of a quarry or of a mine, a plan of restoration of the land, to be pursued during exploitation, be planned and approved by the competent authorities. The plan (Associazione Mineraria Subalpina, 1994; VV.AA. 1993) must include compatibilisation the greatest reinsertion of the mined site into the surrounding environment. This entails planning (VV.AA. 1994; VV.AA. 1989; Furlani Pedoja, 1995; Società Italiana Botanica, 1991) the remediation of the mining site, in such a manner that it is compatible with the existing ecosystem taking in to consideration the geological-technical characteristics of the ground concerned. Consequently, the study and design of the environmental restoration of the areas that have undergone mining extraction, in particular in the case of strip mining, must be deemed an integral part of the general plan of mining. This has made necessary the development of methodologies that enable the technical and economic optimisation of the activities of restoration in a framework of respect of the environment (Cutaia, 1996).

The minimisation of the impact on the environment of restoration activities requires a multidisciplinary approach, that includes the integration of traditional knowledge of extractive and geotechnical engineering with botanical and phyloclimatological, as well as, at times, historical and archaeological information.

This study was applied to a sand ore deposit, significant due to the possibility of wider applicability of the methodologies of analysis and of the solutions examined.

Subsequently, after the description of the mining site under consideration, of the materials extracted and the upcast materials, there are illustrated the analytic procedures used, the physical and chemical parameters of the materials, and the methodologies adopted to obtain the maximum reutilization of the upcast materials, and at the same time, the minimum impact of the mined site on the environment.

DESCRIPTION OF THE MINING SITE

The present work concerns a quartz and feldspar mine from a Pleistocene deposit of fossil sands (Praturlon, 1992) located at Priverno, in the south-west of the Lazio region in Italy.

It is a large deposit, which has already been mined for several years, situated in a foothill zone of a certain importance in terms of nature, landscape and, last but not least, archaeology. The deposit, of alluvial origin and shaped by eolian activity, lies on a limestone formation of the Upper Cretaceous. Into the deposit various interposed layers can be recognised: a surface layer, rich in organic substance and variable in size, and layers of "red" sands, "clay" sands and "white" sands, sometimes mixed together.

The white sand and the mixed sand (with characteristics intermediate between white and red) are of commercial interest. These sands, that overall represent the largest part of the deposit, yield quartz and feldspar destined above all to the glass and ceramic industries and to foundries.

SETTING OF THE PROBLEM

In order to achieve stable environmental recovery of the area under consideration it is necessary to restore a vegetal integument analogous to that of the surrounding environment and thus capable of sustaining and developing itself naturally.

It was necessary operationally to:

- identify the dynamic vegetation series (Blasi, 1994; Farina, 1991; Padula, 1995) suitable to the re-greening of the sandy slopes created by the exploitation activities, with suitable agronomic and pedological characteristics (Belsito, 1993; Spigarolo, 1993).
- to make up a ground similar to the natural one (effecting appropriate mixtures of the materials rejected from exploitation and beneficiation);
- evaluate the aptitude of this blend the waste mixtures for laying in order to ensure the stability of the slopes.

ANALYSIS OF THE SAMPLES OF NATURAL GROUND

In order to make up a blend of soil to sustain vegetation, the reutilization of production cycle waste materials was experimented. These comprise the upper surface layer (strip material), "red" sand (of no commercial value due to its high content of iron and aluminium oxides), the "clay" sand portion of the deposit, and tailings coming from beneficiation (sludge derived from washing the sands, red clays derived from sluicing). The utilisation of these waste materials enables the effective solution of the problem of their disposal, otherwise regulated by the normal law on waste disposal.

In order to corroborate this choice with reliable comparable data, samples of soil and vegetable species were gathered from the land surrounding the mine. The samples were collected from undisturbed sandy slopes with an incline similar to the artificial slopes that were to be rebuilt following the banking of the extracting activity (c. SM14 / ground near the furnaces and with a foot of about 15m).

Two sites were selected, named site A and site B, from each of which three samples of natural ground were collected, subsequently marked A1, A2, A3, B1, B2, B3. The vegetable species present in the sample sites were classified according to the identification of the dynamic series characteristic of the territory: holm-oak series and cork-oak series, Cytisus villosus and Cistus salvifolius shrubs. These species are typical of degraded scrubs and of sandy arid ground with abundance of silica.

The natural soil samples were also physically and chemically characterised (Ministero delle risorse agricole, 1994; Istituto sperimentale per la nutrizione delle piante, 1982; Societa italiana di scienza del suolo, 1985; De Vito, 1995) taking into consideration:

- size distribution (dry analysis with 35, 60, 80 and 100 mesh screens, in accordance with ASTM norms),
- assessment of natural humidity content (in accord with the procedure laid down in ASTM norm D2216-66),
- chemical analyses,
- assessment of the degree of reaction (pH potentiometrically determined on soil/water suspensions).

The previous characteristics evinced that the ground samples with highest content of iron and aluminium hydroxides had the greatest capacity of water retention and thus the highest content of organic substances as been relieved (Figure 1).

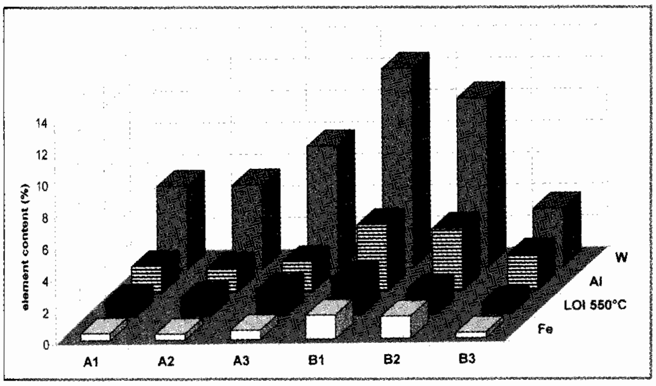

Figure 1. Comparison of some parameters of the natural ground samples. The ordinates are the percentages of iron (Fe), aluminium (Al), water (W) and fire loss (LOI 550 °C) in the ground samples examined.

Comparing these results with the chemical analyses performed on sand samples from the deposit (white, red, mixed sands) that will be discussed below, it clearly emerges that the red sand, with the highest iron and aluminium hydroxide contents, is most suitable for restoration operations (Tables 1, 2).

Composition	Sand		
(%)	White	Mixed	Red
Fe	0,17	0,24	0,29
Si	42,27	38,76	42,10
Al	1,43	1,60	0,90
Ca	0,07	0,06	0,15
Na	0,49	0,23	0,13
K	1,09	0,90	0,71
Mg	0,08	0,02	0,04
Ti	0,02	0,01	0,00

Table 1. Chemical analyses on sand from the deposit.

Composition	Samples					
(%)	A1	A2	A3	B1	B2	B3
Fe	0,45	0,39	0,60	1,51	1,41	0,36
Si	43,16	43,98	42,25	39,26	39,78	42,79
Al	1,70	1,57	1,93	4,22	3,95	2,28
Ca	0,05	0,06	0,08	0,05	0,06	0,04
Na	0,18	0,18	0,20	0,29	0,23	0,34
K	1,10	0,97	1,16	1,24	1,12	1,23
Mg	0,04	0,04	0,06	0,10	0,09	0,03
LOI 550 °C	1,07	1,17	1,63	2,36	1,58	0,75
LOI 1000 °C	0,20	0,28	0,30	0,73	1,42	0,38

Table 2. Chemical analyses on the natural ground samples.

Assessment of the degree of reaction confirmed that the subacidic nature of the soil (pH reading oscillating around 6) for all the materials considered.

The size analysis (of pedological texture, determined by the assortment of primary particles) also evinced that the natural grounds had a greater size assortment than the red sand.

The greater presence of fine particles can be remodelled by mixing the sand with a suitable proportion of clay matter.

The greater presence of aggregates, due to different factors (organic substance, clay sands, presence of salts, organisms and vegetables present in the ground) that concur to link primary particles into secondary ones of greater size (structure of the ground) rather than to one specific component, can be obtained by inducing conditions favourable to the formation of a structure enabling capillary ascent and the retention capacity of the fluid phase. In the case under examination, it is to point up this last characteristic of the ground, as capillary ascent, is of strictly limited importance, as the head water is very deep in relation to the ground surface.

CHARACTERISTICS OF THE DIFFERENT MATERIALS COMING FROM EXPLOITATION AND BENEFICIATION PROCESSES

Having defined the principal characteristics of the natural ground, it was attempted to simulate these starting from five base materials, coming from mining and treatment processes:

- red sand rom (rs);
- red sand: granulometric screened up 60 mesh (60 rs);
- red sand: granulometric screened between 60 and 80 mesh (80 rs);
- strip material rom (s);
- clay material rom (c).

Four sample families were made up. (See Figure 2 for the size composition, in cases which evinced the best pedological characteristics).

Every base material and each made up sample was subjected to the following physical, chemical and mechanical analyses (Ippolito, 1993; Lancellotta, 1993; Sciotti, 1993):

- assessment of the degree of reaction (pH);
- determination of the humi dity content in relation to time (effected over a 24 hour span);

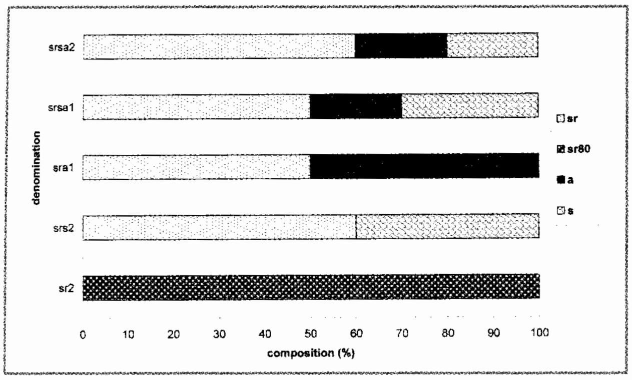

Figure 2. Composition of the made up samples with the best pedological characteristics starting from the following types of materials: (rs = red sand); (rs80 = red sand 60-80 mesh); (s = strip material); (c = clay material).

- determination of the permeability coefficient (according to ASTM norm D2435-90);
- determination of the natural rest angle of the dry material (according to a standard procedure).

For all the mixtures, the pH whose about 6. It should be noted that all the samples made up by strip material evinced higher acidity (Table 3) as was the case in natural samples B1 and B2 (those, as already mentioned above, with the highest content of organic substance).

Samples		pH
origin	denomination	
ground	A1	6,71
	A2	7,09
	A3	7,08
	B1	5,44
	B2	5,84
	B3	6,42
deposit	a	6,24
	s	5,86
	sr	6,52
reconstituted	sr2	5,84
	srs2	5,80
	sra1	6,18
	srsa1	5,97
	srsa2	6,04

Table 3. Value of pH of natural ground samples, of deposit samples, of the best made up samples.

In order to assess the aptitude of the natural and of the made up grounds to imbibe and retain water over time, a series of experiments were carried out utilising a stack of glass columns (Figure 3).

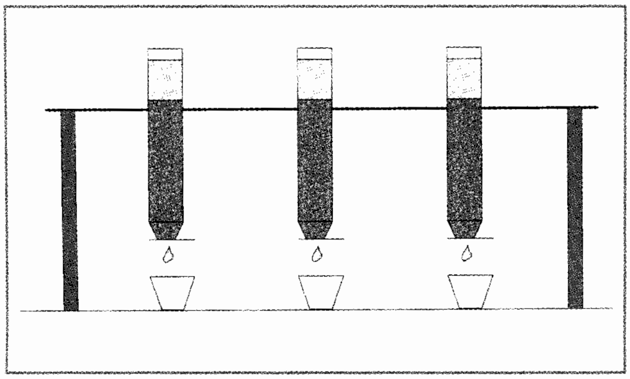

Figure 3. Glass columns used to determine water retention.

On being put into a column, the sample examined was soaked with distilled water in excess in respect to that required for saturation. The residual fraction after percolation corresponds to gravitational water that, in any case, proves unavailable for vegetation growth. The residual water content was measured after 30, 60, 90 and 120 minutes, and 24 hours after the end of the drip phase. It was noted that the water content tends to a minimum value representing the field capacity of the ground; this value is useful for measurement of the capacity of the ground to maintain sufficient water content to enable sustaining of vegetation.

In general the residual water fraction increases with the increase of the content proportion of finest grains of the ground. For this reason the residual water content turned out to be proportional to the clay components (Figure 4).

Minor permeability induced by the clay component results in minor loss of gravitational water (Figure 5).

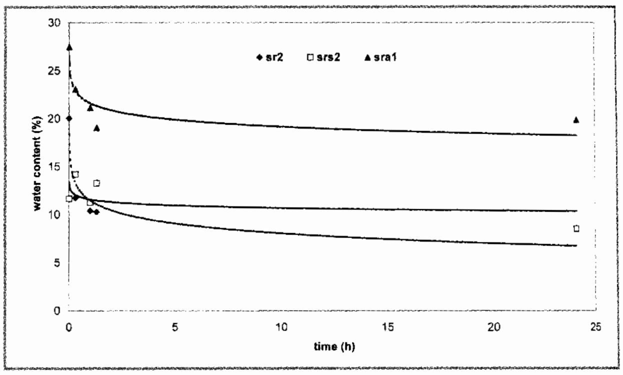

Figure 4. Water content of the samples of each family with the best pedological characteristics.

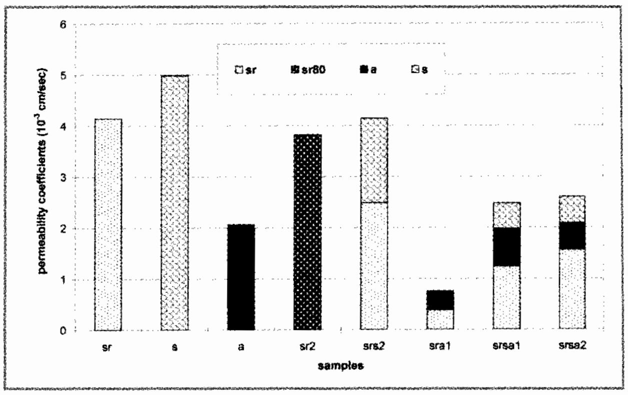

Figure 5. Permeability coefficients of the materials subjected to shear strength tests (compositions of the made up samples are highlighted).

Analysis of the data plotted in Figure 4 further evinces that the strip material gives the ground major capacity to maintain its water content unaltered (lesser inclination of the interpolating curve).

It is thus permissible therefore to surmise that a made up ground, containing clay and strip materials, could guarantee adequate water retention.

In order to choose the most appropriate mixture it is necessary to refer also to the geotechnical characteristics. In fact, if on one side the clay fraction is advantageous as it considerably increases the water retention capacity of the ground, on the other hand it has a negative effect on the stability of the reconstituted slopes.

Therefore shear strength experiments were performed (on dry and saturate samples) on the base materials (red sand rom, clay material rom and strip material rom). The geotechnical characteristics were defined according to the Mohr-Coulomb criterion:

$\tau = c + \sigma \, tg\varphi$

where

τ shear strength (kg/cm^2);

c cohesion (kg/cm^2);

φ friction angle (°)

σ normal load (kg/cm^2).

Such analyses evinced that none of the materials examined had geotechnical resistance characteristics sufficient to guarantee stability of inclination conditions.

The red sand rom and the strip material rom behaved analogously in dry and saturate samples (less cohesion, and friction angle slightly over 33°); the clay material rom evinced not suitable characteristics: despite dry cohesion markedly higher than those above, it had a friction angle insufficient to guarantee stable conditions (Figures 6 and 7).

The direct shear strength tests were calibrated by measuring the natural rest angle for each sample.

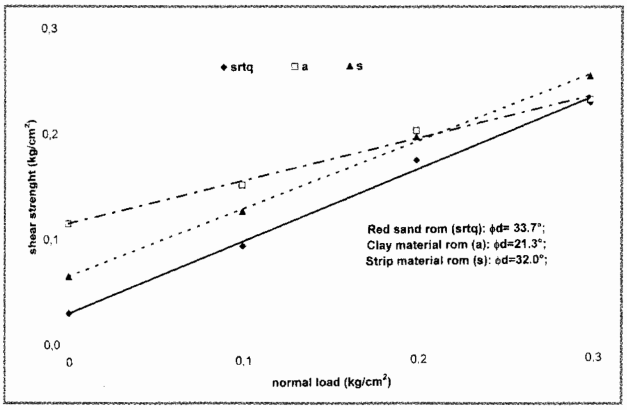

Figure 6. Results of shear strength tests performed on dry base materials.

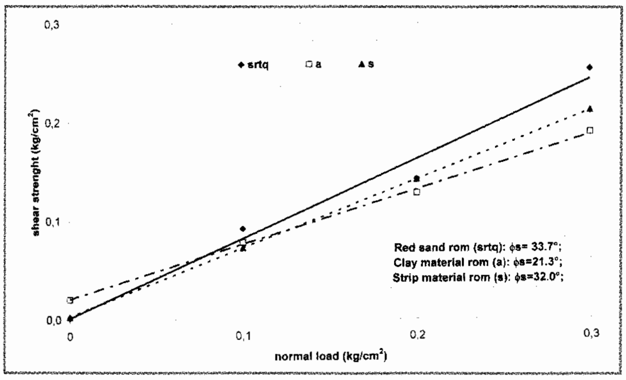

Figure 7. Results of the shear strength tests performed on water-saturated base materials.

IDENTIFICATION OF THE OPTIMAL MIXTURE

Once the hydraulic characteristics of the made up samples had been analysed their geotechnical characteristics were tested in order to ascertain the mixture with the best performance also in this respect. The direct shear strength tests (on dry and saturate materials) were conducted on samples that presented the best water retention capacities for each family of mixtures.

The mixture that, as well as having good water retention characteristics at a certain cohesion, was characterised by an inner friction angle over or equal to 33°, in both the dry and saturate materials, was deemed acceptable.

Two sand mixtures of the three rom components (red sand, strip material, clay material) were identified as having good water retention characteristics and suitable geotechnical characteristics (Figures 8 and 9).

It should be noted that the proper mixture of the three materials enhanced the shear strength capacities of the single materials.

The best characteristics of the three-component mixture could probably be ascribed to different factors, including:

- a better mesh of the various particles due to a greater size assortment;
- the presence of a framework provided by natural fibres present in the strip material.

In the case under examination, the experimental investigation enabled the identification of two sandy mixtures suitable to make up the layer to superimpose over the slopes altered by mining. Such mixtures comprised exclusively materials coming from exploitation and they had the pedological characteristics necessary to host the vegetable species typical to the area. Moreover, they also have geotechnical characteristics suitable to guarantee stability to the slopes.

Thus it is deemed possible to effect the restoration of the area under consideration starting with the utilisation of the mixtures examined.

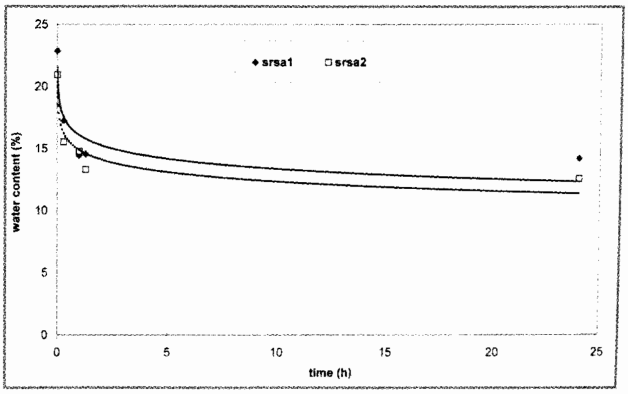

Figure 8. Water content in relation to time in the best samples of made up ground.

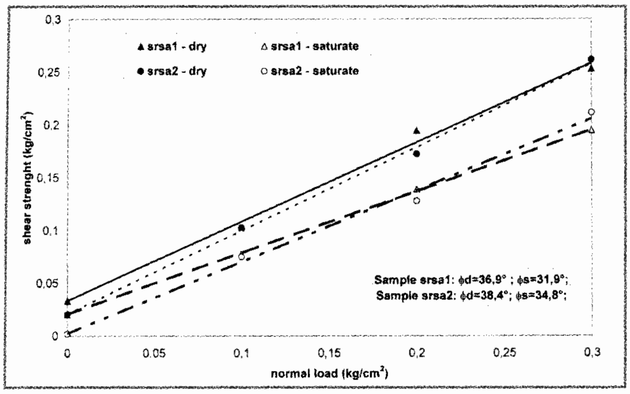

Figure 9. Results of shearing strength tests (dry and saturate) performed on the best samples of made up ground.

CONCLUSIONS

This study has established the procedure to adopt for the made up of ground samples suitable for use in covering abandoned slopes of mining sites.

The procedure is based on the recovery of waste materials and their appropriate admixture in order to ensure the best conditions for water retention, together with adequate geotechnical characteristics.

The methodology proposed, based on multidisciplinary contributions, involves:

- the restoration of abandoned slopes in parallel with the exploitation activities;
- optimisation of the reuse of rejected materials;
- restoration of soils under the control of miners.

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