# LIGHTWEIGHT SCREEDS MADE OF CONCRETE AND RECYCLED POLYMERS: ACOUSTIC, THERMAL, MECHANICAL AND CHEMICAL CHARACTERIZATION

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**Summary**

The paper concerns the use of granulated polymeric materials obtained from sheaths of electric wires, mixed with concrete and water to produce under-floors with good sound and thermal insulating performance. This is a possible solution for the re-use of this typology of waste, so to avoid the disposal into landfills.

Several configurations of the product were tested in the reverberation rooms of the Laboratory of Acoustics according to ISO 140-8 standard, in order to fully characterize the sound insulating properties; the thermal conductivity was measured through the hot box of the Laboratory of Thermotechnics, according to EN 1934. Also mechanical tests were executed in terms of dynamic stiffness according to EN 29052-1 and compressibility according to EN 12431; a chemical analysis completes the investigation of the mixture.

The results show that the product presents satisfying thermal performance, together with good mechanical properties; the chemical analysis of the loose polymers underlined the presence of some chlorinated and polycyclic hydrocarbons. From the acoustic point of view, the sound impact reduction index directly evaluated both with a direct test in the reverberation room and with the indirect estimations through the dynamic stiffness gave results comparable with common materials used for screeds. When the material was tested in conjunction with other typical components of floors, the sound impact reduction index showed poorer performance, underlining that the optimization of the acoustic properties has to be done taking into account of the combination with other floor materials.

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## 1. Introduction

Energy consumption in the building sector can reach up to 40% of the total energy demand of an industrialized country. For this reason, green building strategies can be extremely effective as far as fossil fuel savings and greenhouse gas reduction. Sustainable materials - made from natural or recycled materials - can play an important role, since less energy is generally required for their production than that needed for conventional materials.

In the last years a great attention has been focused on "green" materials, especially in the building sector.



An increasing attention has been turned to natural fibres as alternatives to synthetic ones, in order to combine high acoustic and thermal performance with a low impact on the environment and human health. Recycled materials, such as recycled plastic fibres and recycled rubber mats, can even be regarded as a sustainable alternative, as they contribute to lower waste production and use of raw materials [1].

In particular the recycle of electric wires has grown largely because of the continuous increase of copper value; as a consequence, a huge amount of waste deriving from the poorer part of the cables, such as the polymers of sheaths, is produced and any application that could employ this kind of material becomes of great interest.

Figure 1. Image of the loose polymers and enlargement of the aggregate.

In the present research, the recycled polymers are used in a mixture with concrete and water to obtain a lightweight screed; the polymers blend is prepared in compliance with the Italian Standard UNI 10667-14 [2] for requirements of polymeric materials to be used as aggregate into mortar of cement (fig. 1).
The material obtained is a levelling and smoothing aggregate, pumpable, that could be also used as filling materials in excavations for pipes (water, gas, sewer and telephone cables), in buildings and roads foundations, and as slopes reinforcement.
The goal of the paper is to preliminarily define the properties of the mixture from the acoustical and thermal points of view, giving also an overview on mechanical and chemical features, to complete the characterization.

## 2. Mechanical and chemical analysis

The Italian standard UNI 10667-14 defines the requirements of polymeric materials to be used as aggregate into mortar of cement. The requirements include the content of plastic, rubber, metals and other materials, the apparent density, the granulometry, the colour, the shape (chip, granule, pellet), and residual moisture
The granules obtained by grinding the sheaths of electric wires are almost completely made of plastic and rubber (99,92 % in weight), while only 0,08 % is metal.
The apparent density has been measured in compliance with ISO 61 [3]: the mean value is 774 kg/m$^3$.
The granulometry has been defined using three sieves with different cell dimensions: 5, 2 and 1 mm. The results are reported in Table 1.

Table I. Percentage of the granules passing through the sieves.

| > 5 mm | 2-5 mm | 1-2 mm | < 1 mm |
|---|---|---|---|
| 0,00 % | 13,8 % | 54,5 % | 31,7 % |

Finally the residual moisture is reported in Table 2.

Table II. Percentage of residual humidity.

| Initial mass of the sample (g) | Mass of the dried sample (g) | Percentage of residual humidity |
|---|---|---|
| 100,83 | 100,22 | 0,60 % |
| 99,84 | 99,21 | 0,63 % |
| | Mean value | 0,62 % |

The aim of the mechanical tests is to define the thickness variations of the survey under the application of different loads; the reference Standard is the EN 12431 [4].
The samples were produced using the following components:

- mixture of recycled polymers produced according to the UNI 10667-14 (density = 774 kg/m$^3$);
- cement 325 (loose, 1500 kg/m$^3$);
- water (1000 kg/m$^3$).

The same mixture was used also for thermal and acoustic tests.
The samples were given a square shape, 0.200 m side. Two metallic plates guarantee a uniform distribution of pressure on the sample surfaces, constituting, at the same time, the reference for the precision (10 μm) dial gauges (fig. 2).
In Table 3 the results obtained for the three load levels are reported.


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The compressibility measurement evidences the remarkable ability of the aggregate to resist to great loads, confirming the possibility to use it for floor screeds.

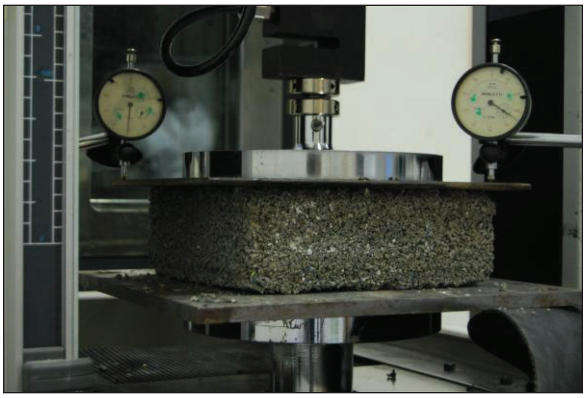

Figure 2. experimental setup for the mechanical test.

Table III. Thickness variation as a function of load.

| | $d_L$ (250 Pa) | $d_F$ (2,000 Pa) | $d_B$ (50,000 Pa) |
|---|---|---|---|
| **Thickness variation (mm)** | < 0.1 | 0.4 (± 0.1) | 0.7 (± 0.1) |

As far as the chemical analysis, a characterization of Volatile Organic Compounds (VOC) emissions was executed by means of gas-cromatography, according to method of solid-phase microextraction [5].
An amount of about 1.4 μg/g of chlorinated hydrocarbons were found, mainly constituted by chloroform; besides, a smaller amount (about 0.4 μg/g) of other hydrocarbons (polycyclic, mostly toluene) was detected.
It has to be underlined that the analysis was conducted on the recycled polymers as loose material: when the composite is mixed to form the screed, the single plastic pieces are trapped in the cement matrix, therefore, the formation of VOC is substantially reduced.

## 3. Acoustic properties

### 3.1 Dynamic Stiffness

Dynamic stiffness is a fundamental parameter for resilient insulating layers; since it directly influences the efficiency of the material in impact noise damping.
The EN 29052 part 1 [6] specifies the test method for determining the dynamic stiffness of resilient materials used under floating floors; the definition of dynamic stiffness given by the standard is:

$$s' = \frac{(F/S)}{\Delta d} \qquad (1)$$

where F is the force applied perpendicularly to the sample, S is the surface of the sample and Δd is the resulting dynamic variation of the sample thickness.
The test method prescribes the evaluation of the resonance frequency fr of the fundamental vertical vibration of the mass-spring system constituted by the resilient material (spring) and the load plate (mass); the apparent dynamic stiffness s't is calculated by means of the equation:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{s'_t}{m'_t}} \rightarrow s'_t = 4\pi^2 m'_t (f_r)^2 \qquad (2)$$

where $m'_t$ is the load mass per area unit.
The sample (200 mm x 200 mm) under test is placed under a steel load plate (weight = 8 kg, $m'_t$ = 200 kg/m$^2$). Force is applied by means of a shaker fed by a sweep signal, while the frequency resonance is evaluated by means of two accelerometers. Tests have been executed in reverberating rooms in order to get rid of external disturbance (vibrations, steps, etc…).
Dynamic stiffness is also useful for a preliminary estimation of the reduction in impact sound pressure level $\Delta L_W$ through the following relation [7]:

$$\Delta L_W = 18 + 15 Log\left(\frac{m'}{s'}\right) \qquad (3)$$

where m' is the mass on the floating floor in kg/m$^2$.
Another important parameter that has to be considered is the damping ratio δ, defined as the inverse of the quality factor Q:

$$Q = \frac{f_s}{f_2 - f_1}, \ \delta = \frac{1}{Q} \qquad (4)$$

where $f_s$ is the measured resonance frequency and $f_1$ and $f_2$ are the values of the frequency on the resonant curve at –3 dB of the resonance frequency (see figure 3).

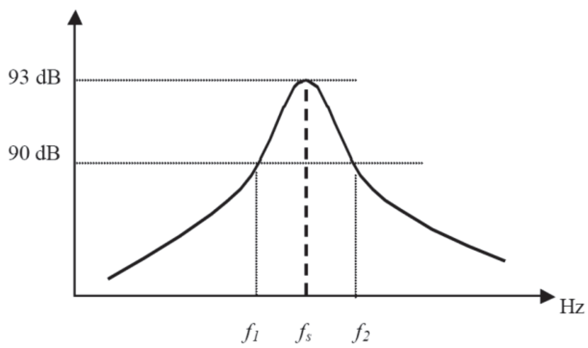


Figure 3. Resonant curve with the indication of $f_s$, $f_1$ and $f_2$ values [8].

As stated by Pavoni Belli et al. [8] the accuracy of the estimation of $\Delta L_W$ decreases with the decrease of the damping ratio. If the value of the damping ratio exceeds the 20%, the $\Delta Lw$ estimated by dynamic stiffness has an error around 1 dB; differently, the error could be higher than 3 dB .

The dynamic stiffness test were carried out on three samples prepared varying the concentration of their components (polymers, cement, water) but keeping constant the thickness (0,07 m).

Table 4 reports the average results of the measurements of dynamic stiffness for the three samples.

Table IV. Results of dynamic stiffness tests.

| *Sample* | *Density ($kg/m^3$)* | *Resonance frequency (Hz)* | *Apparent dynamic stiffness s't ($MN/m^3$)* | *Damping ratio (%)* |
|---|---|---|---|---|
| A | 740 | 85.5 | 58 | 12.6 |
| B | 766 | 107.9 | 92 | 11.1 |
| C | 800 | 112.7 | 100 | 9.1 |

The samples are made from a mixture of concrete so the flow resistivity can understandably be considered higher than 100,000 Pa. Therefore the apparent dynamic stiffness $s'_t$ coincides with dynamic stiffness s'.

As expected, the value of dynamic stiffness decreases with density.

In particular, the dynamic stiffness of sample A (58 $MN/m^3$) is a fairly good value for a concrete-based screed. Moreover the estimation of $\Delta L_W$ through equation (3), could be more accurate for sample A rather than sample C, due to its higher value of damping ratio.

### 3.2 Impact sound pressure reduction

Tests on the proposed materials were executed using two contiguous reverberating rooms (one above the other): the upper is called emitting room, the lower is defined as the receiving room. They are separated by a heavyweight standard floor where the screed to be analyzed is positioned (fig. 4). The reference Standard for the evaluation of the reduction in impact sound pressure level ΔL is ISO 140-8 [9] (now replaced by ISO 10140-3 [10]).

Despite it is common knowledge that tests on 1 square meter sample are not fully representative of the real behavior of the floating floor, it was not possible to set up a larger sample because of the lack of material.

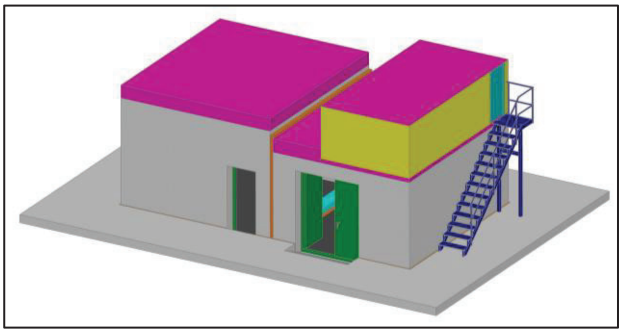

Figure 4. Scheme of the reverberating rooms placed one open the other (in yellow the emitting room).

A 7 cm lightweight screed alone was tested: the results cannot be considered acceptable as the surface of the survey was damaged by the hits of the tapping machine hammers (fig. 5).

Figure 5. View of the surface conditions at the end of the analysis.

A possible application of the lightweight screed was tested in the following configuration .

- 8 cm lower lightweight screed (density ≈ 800 $kg/m^3$, dynamic stiffness ≈ 100 $MN/m^3$);
- 0.6 cm reticulated polyethylene underlayer for floating floors (dynamic stiffness = 45 $MN/m^3$);
- 6 cm upper screed (density ≈ 1800 $kg/m^3$) and porcelain gres tiles.

The results in terms of the reduction of impact sound pressure ΔL are reported in figure 6.

The index $\Delta L_W$ calculated in compliance with ISO 717-2 [11] is 17 dB.

Equation 3 can be used to evaluate the $\Delta L_W$ of the above mentioned system. The mass of the floating floor, m', can be considered around 100 $kg/m^2$, while the dynamic stiffness of the lightweight screed coupled to the underlayer was calculated using equation 5:

$$s' = \frac{1}{\sum_{i=1}^{n}\left(\frac{1}{s'_i}\right)^{-1}} \qquad (5)$$

where $s_i$ is the dynamic stiffness of the i-th layer.


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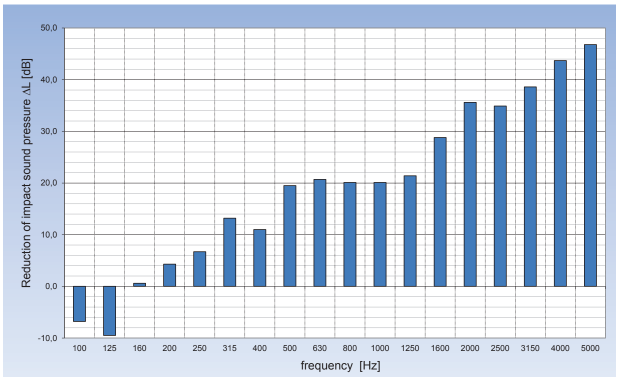


Figure 6. Reduction of impact sound pressure level ΔL vs frequency.

The global dynamic stiffness of the system composed by the lightweight screed and the underlayer calculated through equation 5 is 31 MN/m$^3$. Consequently, using equation 3, the estimated $\Delta L_W$ of the system is 25.6 dB.
The estimated (25.6 dB) value of $\Delta L_W$ is definitely different from the measured one (17 dB).
Possible reasons for this mismatch can be identified in the following assumptions:

- the surface of the sample is small (1 square meter) and the influence of the edges can become important;
- EN 29052-1 is used to test resilient materials used under floating floors in dwellings which thickness is usually of the order of millimeters or 1-2 centimeters; in this case the sample is a 7 cm thick screed.

## 4. Thermal properties

The thermal conductivity of the aggregate has been determined through a hot box system, according to the procedure described in the Standard EN 1934 [12]. This method was preferred to other measurements systems, such as the guarded hot plate and heat flow meter method, which require smaller dimensions samples, so being more affected to local discontinuities derived from imperfect mixing.
The hot box setup realized in the Laboratory of Thermotechnics of Perugia University is made of two similar rooms (a hot and a cold one), with the following measures: 1.98 x 0.90 x 2.68 m (fig. 7); it was tested a 10 cm thick rectangular sample (1.23 x 1.48 m), prepared respecting the same proportion of the mixture used for the acoustic and dynamic stiffness tests. The survey is blocked in the support structure through a series of compressed air jacks. Figure 8 reports the trends of the temperature inside the two chambers.

Figure 7. Hot box setup and sample view with sensors.

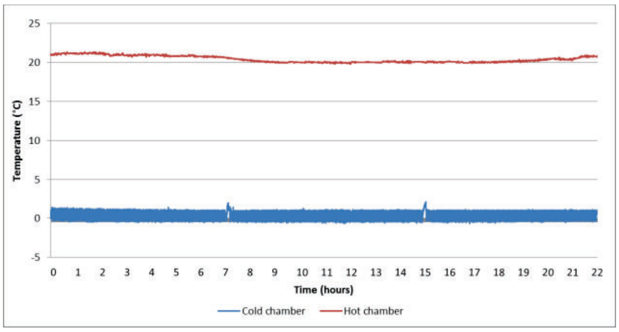


Figure 8. Trend of air temperature in the two chambers of the hot box.

The thermal conductivity value obtained from the tests is 0.189 W/mK, with a measurement uncertainty equal to 4.3 %, evaluated according to ENV 13005 [13].
If these results are compared with the characteristics of concrete used for common screeds (thermal conductivity value around 0.800 W/mK), the improvement in thermal insulation becomes evident. Furthermore, the performance remain effective even if the comparison term is constituted by a traditional lightweight screed, which presents thermal conductivity values close to 0.400 W/mK.

## 5. Conclusions

The granulated polymeric materials obtained from sheaths of electric wires after the recycle of copper could be used in a mixture with concrete and water to produce lightweight under-floor screeds.
The tested material revealed a good mechanical behavior, while the chemical analysis underlined the presence of some chlorinated and polycyclic hydrocarbons for the loose polymers. The presence of these volatile components is probably

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reduced when the plastic is confined in the cement mixture.

A preliminary analysis showed good performance in terms of thermal insulation properties (measured thermal conductivity = 0.189 W/mK), if compared with common concrete (0.800 W/mK) and typical lightweight screeds (0.400 W/mK).

As far as acoustic properties, dynamic stiiffness was measured for three different compositions of the sample.

The lighter sample showed a good value of dynamic stiffness (58 MN/$m^3$), demonstrating that also from the acoustic point of view the material has a good potential.

Finally the reduction of impact sound pressure for a system including the lightweight screed was measured in laboratory in compliance with ISO 140-8. However the results cannot be considered representative of the real performance of the material because of the small surface of the sample (1 square meter). Infact there is a significant mismatch between the estimated and the measured value of $\Delta L_{W}$.

The investigation will be prosecuted measuring the reduction of impact sound pressure level for larger sized samples (at least 10 square meters), possibly varying some parameters such as the mixture composition and the thickness of the screed.

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