Non-conventional textile structures with technical destination, designed and developed at S.C. Cora Trading & Service S.R.L.

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REZUMAT – ABSTRACT

Structuri textile neconvenționale cu destinație tehnică, proiectate și dezvoltate la S.C. Cora Trading & Service S.R.L.

Wool fibers are a natural, renewable, sustainable, low impact on the environment, with huge potential for humanity. Given the exponential growth of the Earth’s population, raw materials are getting less and less, a business based on the processing of renewable raw materials, especially wool fibers, has a high chance of survival and development.

Romania, with an overwhelming agrarian economy, has a population of nearly 10 million sheep and a production of over 16,000 tons of medium and coarse wool. Given the need to set minimum energy performance requirements for new buildings and for the major renovation of existing ones at European Union level, the development of new materials and technologies is necessary, so that the opportunity to capitalize on wool for buildings be a workable item on long term.

This paper presents the experimental results of the characteristics of 4 non-conventional textile structures (UTS) made of 100% wool fibers, designed and developed at S.C. Cora Trading & Service SRL, on their existing adapted technology. The fibrous blend used, consisting of both tanning wool and coarse shared wool allow development of innovative structures, with potential of use for their thermal insulation capacity and great potential of sustainable development of the manufacturer.

Keywords: coarse wool fibers, tanned wool fibers, non-conventional textile structures, thermal conductivity

INTRODUCTION

European Union targets by 2030 include creating a cleaner and healthier climate. Investments for improving energy efficiency in buildings, related to ensuring a clean, non-polluting environment in a sustainable way are a priority of the governments of the European Union countries, in the context of the reduction of greenhouse gases [1, 2, 3].

Under the Energy Performance of Buildings Directive, EU countries have to set minimum energy performance requirements for new buildings and major renovation of existing ones [3]. In this directive, the action “Accelerating the European Energy System Transformation” refers to “Developing new materials and technologies, energy efficiency solutions for buildings”. It is estimated that Romania will become one of the largest European sheep breeders, sheep reared for meat, so the opportunity to exploit wool in construction can be a long-term exploitable item.

Wool has a huge potential for the use of technical textiles [5, 6], thanks to its essential and unique characteristics such as: thermal resistance of high values, even in humidity conditions; capacity to minimize thermal and heat variation in humidity conditions; moisture management capacity; capacity to minimize condensation (does not favor mold growth), absorption capacity of volatile organic compounds, formaldehyde, sulfur dioxides, nitrogen oxides and carbon dioxide in the atmosphere; hypoallergenic and non-toxic character [7]; airborne and surface noise reduction capacity (reduction factor ≥ 90%), heat transfer capacity, self-extinguishing capacity in contact with...
fire sources, biodegradable and compostable character [8, 9, 10]. The paper proposes the presentation of experimental results of non-conventional textile structures (NTS) from 100% wool fibers, designed and developed at S.C. Cora Trading & Service SRL, on their existing adapted technology, with potential for use in the field of construction, thanks to the thermal insulation properties [11, 12, 13, 14]. The particularity of these structures is the presence in the fibrous blend of both tanned wool fibers and sheared thick wool fibers, with a low degree of valorization, currently, in Romania.

EUROPEAN CONSTRUCTION MATERIAL MARKET

Thermal insulation materials in buildings, which amounted to ~ 7.4 million tons in 2014, corresponding to a volume of ~ 234 million m³, are essential for increasing energy efficiency in buildings, as construction consumes more than 40% of the amount of energy of the European Union and account for about 35% of all greenhouse gases [3]. Old buildings have the greatest potential for increasing energy efficiency (~ 36% by 2030). The annual compound growth rate of the production and consumption of thermal insulation materials is projected to be 4.5% by 2027 [3]. The market of thermal insulation materials in buildings is vast, with several identified classes, which are presented in the table 1.

The competitiveness of the thermal insulating material market is affected by the increasing demand, the improvement of the standards in the field, the requirements for improving the quality of insulating materials and the reconfiguration of the European construction industry [3, 4, 15]. The distribution chain of thermal insulation materials is shown in figure 1.

The essential parameters that are taken into account both by manufacturers and by the end users of thermal insulation are: the thermal insulation potential, the environmental relation, the protection factors (fire resistance) and the price. An element that plays a significant role in calculating the cost of an insulation material is the provided safety and the quality of the insulated interior air [1, 16]. In this context, fire behavior is carefully studied, both in terms of damage in the event of a fire, but especially because of the toxic gases that it discharges during combustion. These gases can cause serious illness or even death [2].

Although the structures derived from organic, vegetal and animal materials occupy a secondary place in the thermal insulation market in the European Union (thermal insulation of wool occupying 1%), their development potential is very developed in the conditions of sustainable development [4]. Thermal wool insulation does not support burning. Due to the nitrogen (16%) and sulfur (3–4%) content, in the chemical structure, wool fibers show the highest fire resistance of natural fibers (flame resistant fibers) (table 2). The assessment of the degree of flammability (the ability to ignite and burn) in textile materials is done by determining the limiting oxygen index (LOI – %) [16]. Wool textiles protect (temporarily) the propagation of outside fire inside a home or vice versa, and when exposed to the flame they do not release toxic substances [1, 16].

MATERIALS AND METHODS

In order to obtain an experimental model (EM) of non-conventional textile structures (NTS) [18], a fibrous blend was designed, as shown in table 3 [17, 20, 21].

| No. | Class                  | Type                                                                 |
|-----|------------------------|----------------------------------------------------------------------|
| 1   | Inorganic mineral fibrous | Stone wool; glass wool; slag wool                                    |
| 2   | Organic fossil fuel derived | Polyurethane (PU); Expanded polystyrene (EPS); Extruded polystyrene (XPS); Polysiocyanurate (PIR); Phenolic foam |
| 3   | Organic plant/animal derived | Cellulose; Woodfibre; Cork; Sheep’s wool; Cotton; Hemp; Flax; Compressed straw |
| 4   | Innovative              | Biopolymers; Nano-coatings; Aerogel; Vacuum insulation panels; Nano-cellular foam; Phase change materials (PCM); Advanced insulation foams |
| 5   | Other                   | Cellular Glass; Aerated glass; Vermiculite; Expanded clay pellets; Foil products |

Table 1

| LOI limiting oxygen index (%) – minimum oxygen quantity to burn | Materials with LOI>25% burn quickly | Materials with LOI<25% do not support burning |
|------------------------------------------------------------------|-------------------------------------|---------------------------------------------|
| Sheep wool                                                       | 25.2                                |                                             |

Table 2
The main characteristics of blend recipe are presented in table 4. The designed fiber blend was processed on two adapted technological flows, available at SC Cora Trading & Service (figure 2), which includes 5 preliminary processing operations, web and batt forming operations, mechanical bonding operations (to obtain NTs) and final finishing operations [10, 19, 20] (table 5). The high degree of impurities imposed the use of 5 primary processing operations, which can eliminate about 50–60% of these matters (vegetable matter and dirt) [21].

## EXPERIMENTAL
Using the technologies presented in figure 2, four experimental models (EM) of NTS, encoded S1 (figure 3, a), S2 (figure 3, b), S3 (figure 3, c) and S4 (figure 3, d) were made. The four NTS vary function of thickness, specific mass (density) and bonding/felting technology. The NTS experiment matrix (identified in figure 3, a – S1, figure 3, b – S2, figure 3, c – S3 and figure 3, d – S4) is shown in table 6.

### TECHNICAL SPECIFICATION ON THE VARIATION LIMITS OF THE FIBER BLEND CHARACTERISTICS

| Fiber characteristics            | Value          |
|----------------------------------|----------------|
| Diameter, µm                     | Average 32,986 CV, % 36,855 |
| Length, mm                       | 64,33 74,97   |
| Elongation to break, %           | 29,675 0,460  |
| Breaking force, cN               | 30,825 0,637  |
| Content of impurities, % (vegetable + mineral) | 0,8 - |
| Soluble substances in organic solvents, % | 4,06 - |
| Index of solubility in alkali, % | 12,69 - |

### TECHNOLOGICAL PARAMETERS FOR NON-CONVENTIONAL TEXTILE STRUCTURES PRODUCTION, AVAILABLE TO SC CORA TRADING & SERVICE SRL [22]

| Technological Flow stage | Technological operation | Equipment | Characteristic |
|--------------------------|-------------------------|-----------|----------------|
| Preliminary processing   | Fleece supplying        | -         | Bales, sacks   |
|                          | Fleece sorting          | -         | Manual operation |
|                          | Fleece cutting, mineral impurities mechanical removing | 2 knives rotary cutter – invention | Productivity: 200 kg/h – one pass; Cutting length: 100 mm |
|                          | Fleece opening          | Fleece opening equipment – invention | Productivity: 50 kg/h – one pass |
|                          | Willowing               | Technological adapted opening willow | Productivity: 200 kg/h – one pass |
| Web formation            | Carding                 | HBD Card  | Productivity: 40 kg/h; Web’s specific mass: 20g/m²; Web’s width: 1.80 m |
| Batt formation           | Cross-lapping           | Technological adapted transversal crosslapper | Web layers/m: 15; Batt’s specific mass: 240 g/m²; Batt’s width: 180 cm – 250 cm |
| Mechanical bonding       | Needle-punching         | Asselin single board needle loom | Maximum width: 6,5 m; Maximum thickness after needle-punching: 4 cm; Maximum specific mass: 7 kg/m²; Maximum density: 0,35 g/cm³ |
|                          | Felting – hardening     | Hardener – Technologically adapted flat installation | Maximum width: 220 cm; Streaming length: 3 m; Top platen length: 3m |
| Finishing processing     | Cutting, dimensioning   | Circular knife, guillotine | Panels, rolls |
|                          | Packaging, labelling    | -         | PE foil        |
The technological variants of EM: S1, S2, S3 and S4, in the form of fibrous panels, have been analysed in terms of field of use specific functionalities: physical analysis (mass/unit area, thickness) and functional (thermal conductivity, fire behaviour, electrical resistivity).

RESULTS

Mass per unit area

The mass/unit area of the structures was obtained by overlapping the fibrous batts obtained from cross-lapping, weighed in advance.

A number of batts have been folded successively until aim posed specific mass and weight, possible to consolidate, is reached. The values obtained are shown in table 7.

Regarding the specific mass of S1, S2, S3 and S4 NTS, for the obtained values it can be mentioned that S2 has a specific mass by 17.29% lower than S1, this being the minimum specific mass, possibly obtained by this bonding technology. Below this value, keeping the consolidation conditions constant (including the height), the mechanical bonds between the fibers are not secured, so the structure does not get mechanical resistance. In the case of S3 and S4, the consolidation technology allows obtaining large specific masses at smaller thicknesses than the S1 and S2.
structures. S3 has a specific mass greater than 203.15% over S4. The four technological variants are potentially different for recovery in the construction area, given the specific mass differences.

**Thickness**

The mechanical bonding by steam hardening allows high-porosity structures to be obtained (higher volumes than bonded reinforced structures by other modes) (figure 4). For structures S1 and S2 a height of the oscillating table of the hardening equipment has been calibrated at 60 mm. The results obtained from the measurements are presented in table 8.

Due to the different specific mass, after the bonding operation, the S1 and S2 structures did not remain at the calibrated height but decreased by 33.76% (S1) and 18.8% (S2), respectively. The thickness of S2 is 22% greater than S1. The S3 and S4 structures are more compact, with smaller thicknesses than the S1 and S2 structures, as the bonding technology allows barbed needles to train the fibers in order to fix them through the interstices of said fibrous batt (rendering compactness). Structure S4 is 55% thicker than S3.

**Thermal conductivity**

The thermal conductivity $\lambda$ [W/mK] is equal to the amount of heat that passes for 1 hour through a 1 m thick material with a surface area of 1 m$^2$ and a temperature difference on the two faces of its 1 degree Celsius [23]. The value of $\lambda$ is a material constant, and its decrease leads to an increase in the level of thermal insulation that the material can provide. Values of $\lambda$ for STN S1-4 are presented in the table 9. Figure 5 shows that the $\lambda$ value of structure S2 is 4.07% smaller than S1, which means that structure S2 is better isolator than structure S1 (structure S2 has a larger air volume than structure S2, which allows a higher convective transfer that structure S1). Structure S4 shows an $\lambda$ value of 15.34% lower than S3.

**Burning behaviour of NTS**

Fire behaviour test: Determination of flame propagation properties on vertically oriented specimens consists of two procedures: A. ignition of the surface, B. ignition of the lower end. The results of the fire tests of the S1, S2, S3, S4 structures (the height of the footprint) are shown in table 10.

| Characteristics                  | Reference document       | EM technological sample |
|----------------------------------|--------------------------|-------------------------|
| Average thickness, mm            | SR EN ISO 9073-2-2000    | S1 = 39.744, S2 = 48.669, S3 = 19.173, S4 = 9.102 |
| CV, %                            |                          | S1 = 1.019, S2 = 1.742, S3 = 3.424, S4 = 1.210 |
| Calculated density, kg/m$^3$     |                          | S1 = 53.89, S2 = 36.35, S3 = 133.03, S4 = 96.76 |

| Characteristics                  | EM technological sample |
|----------------------------------|-------------------------|
| Average thermal conductivity, W/mK| 0.0378 S1, 0.0362 S2, 0.0392 S3, 0.0332 S4 |
| CV, %                            | 0.1186 S1, 0.1425 S2, 0.8697 S3, 0.1590 S4 |
burned hooves; The trace dimensions due to the initiation flame of 40 ± 2 mm (procedure A) and 25 ± 2 mm (procedure B) are higher in high-volume structures (S1 and S2) than in high density structures (S3 and S4), both longitudinally and transversally, for both procedures. The smallest trace shows the S4 structure in fire testing by both procedures.

Electrical resistivity

Testing the electrical resistivity of wool fiber panels confirms their dielectric character. The average resistivity test values are shown in table 11. From the analysis of the experimental values we find that the values are ranged between $10^{13}$ (Ω) to $10^{14}$ (Ω), both for surface resistivity and for the resistivity of the volume, values above the resistivity values of dielectric insulating materials ($10^{11}$ Ω), comparable to the prexiglas, teflon, air etc. [12]. It can be appreciated that the use of structures S1, S2, S3 and S4 in construction structures traversed by electric cables does not pose additional risk in case of short electric circuits.

CONCLUSIONS

The study reveals the potential for the use of wool fibers in non-conventional textile structures for thermal insulation in construction. The experimental fibrous blend consists of tanning wool, considered as tannery waste and sheared coarse wool. For the experiments two existing technological flows, at S.C. Cora Trading & Service SRL, for processing the fibrous blend were selected, which contain preliminary processing operations, web and batt formation and final operations. Due to the high content of impurities of mineral, animal and vegetal origin, the fleece has been subjected to 5 preliminary processing operations, where the manufacturer’s own invented or with specific technological adaptations equipment was used. For the experiments 4 technological samples of non-conventional textile structures, formed by two ways of bonding/felting (hardening – structures S1 and S2), needle punching – structures S3 and S4) have been used. The 4 non-conventional textile structures designed and developed represent a sustainable developing potential for the manufacturer particularly and for the Romanian textile industry generally.

ACKNOWLEDGEMENTS

This work was carried out under the PNIII, Programe 2: P2 – Increasing the Romanian economic competitiveness through RDI, Subprograme 2.1. Research, development and inovation, Innovation Checks 2018, Program implemented with the support of the Executive Agency for Higher Education, Research, Development and Innovation Funding, project no. PN-III-P2-2.1-CI-2018-0870 and the publication is funded by the Minister of Research and Innovation through the Program 1 – Development of the National Research and Development System, Subprogram 1.2 – Institutional Performance – RDI excellence funding projects, Contract no. 6PFE/16.10.2018.

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