18th AUTEX World Textile Conference, June 20-22, 2018, Istanbul, Turkey

Paper ID no 3564

Recovery of mineral dust in composite materials

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Abstract This work evaluates the potential of use of mineral dust waste from stone extraction and processing industries to develop composite materials to construction sector. Actually, a high volume of mineral waste was generated, in a stone extraction and processing industries, without any type of recycling and recovery. In this work, this waste was combined with a biopolymeric material, with different mass ratios, namely 70:30 and 50:50 of mineral waste and polymeric material. To accelerate the curing process, a compression moulding process was used. After that, a several characterization tests were performed, in order to compare the main properties of the composite materials obtained with different mass ratios of mineral dust and polymeric material. The physical and mechanical tests were performed to evaluate the density, moisture absorption, flexural strength and flexural modulus. Besides that, the thermal properties were obtained using an Alambeta testing device. The experimental results show a decrease of density of the composite materials from 2.7 g cm^{-3} to 2.03 g cm^{-3}, compared with virgin slate rock. In terms of mechanical performance, an increase of flexural strength from 17.1 MPa to approximately 80 MPa was verified between Viroc and the composite materials obtained. In addition to this, an HB rating on flammability test guarantees to the composite materials an excellent capacity to fire resistance. These results allow to conclude that the recycling and recovery the slate waste has a big potential of application in several areas, such as construction one.

***Keywords*—Recycling, mineral waste, composite materials, mechanical properties.**

I. Introduction

THE technology development and the world population growth has led to an overuse of resources, both natural and synthetic ones, which has aroused several concerns about environmental sustainability.

In fact, exponential growth has taken place in the world population, being expected to reach 9 billion in 2042, compared to 3 billion in 1960 [1]. This has led to the use and development of new materials and products, which can respond to these increasing needs and trends. Consequently, an increase in composite materials use has been noticed mainly in construction and automotive areas, replacing conventional materials. In addition to the costs and weight reduction of components, these materials also allow to increase some mechanical properties and corrosion resistance. Actually, the most used materials as reinforcement have been synthetic fibres such as carbon and glass. The use of these materials has effectively allowed the positioning of the composite materials in higher level of the value chains. However, in an era dominated by concerns about environmental sustainability, the use of natural and recyclable materials on composites has gained paramount importance. Several scientific groups and researchers have been looking for development of composites with natural materials as reinforcement and the replacement of thermosetting matrices to thermoplastic ones.

In this context, the use, recovery and recycling of the materials into new raw materials to another ones is one of the main trends actually verified.

In Portugal, some of the main wastes generated includes the mineral dust, mainly from the stone extraction and processing industries. Approximately 85% of the mineral dust come from the cutting and treatment processes of these industries. Moreover, it is estimated that by processing each ton of mineral based products, about 30 tonnes of waste is generated, without any type of recovery or recycling, thus causing a high environmental impact [2].

So, in this context, the goal of this study is the recycling of this waste, in powder form, and combination with polymeric materials, in order to develop new value-added products to construction design area.

II. Materials and Methods

A. Used Materials

The mineral dust used is come from slate rock, which is a metamorphic rock composed essentially by silicate and clay elements. This waste, illustrated in Fig.1, is essentially generated from the extraction and sanding processes. This type of rock has a density of 2.7 g cm^{-3}, a flexural strength of 42.5 MPa and a moisture absorption capacity of 0.46%.

Epoxy resin, a thermosetting polymer, was supplied by Sika, reference SR GreenPoxy 56, with up to 56% of its molecular structure coming from plant origin, becoming this polymer an ecological environmentally friendly resin. This percentage is a function of the carbon origin contained in the epoxy molecule. This resin is out coming from the latest innovations in bio-based chemistry. SR GreenPoxy 56 has a density of 1.198 g cm^{-3} and a viscosity of 800 mPa s at 25°C.

Fig. 1. Mineral dust waste used

B. Composite Materials Production

The composite materials were developed through two main steps. Firstly, the mineral dust waste and bio-epoxy resin were mixed until a homogeneous mixture is obtained, at different mass fractions, as explained in Table I.

After that, the mixture is placed in an appropriate mould and the cure process is accelerated through a compression moulding process in a specific equipment, showed in Fig.2, at 80ºC and 6 tones, during 10 min.

After this heating step, the samples were cooled at room temperature until complete curing of the resin.

TABLE I
Composition of Composite Materials

Sample	Mineral dust waste (%)	Bio-Epoxy Resin (%)
1	50	50
2	70	30

Fig. 2. Molding compression equipment

C. Characterization Tests

The obtained samples were subsequently subjected to several characterization tests. The flexural tests were performed in accordance to EN ISO 178 standard, using samples of 80 mm length, 10 mm width and 4 mm thickness, at a crosshead speed of 5 mm min^{-1}. At least seven specimens were tested for each sample. From the obtained data, it was possible to determine the properties of max stress and flexural modulus of the composite materials produced.

The thermal tests were performed by Alambeta device with 55 mm radius circular samples. This device measures the thermal resistance of these materials to the heat flux, and the properties of thermal conductivity and thermal resistance are obtained. Then, with this test, it was possible to determine the thermal insulation properties.

The moisture absorption test, with an analytical balance, allowed to measure the content of moisture absorbed after 24 hours. The used equipments in both tests are presented in Fig. 3.

Fig. 3. Alambeta device and analytical balance for thermal and moisture absorption tests, respectively

Finally, the flammability test was performed, according to UL94 standard, in a Atlas HVUL2 chamber flammability, in order to evaluate the combustion rate of these composite materials. This test allows to determine de flammability of polymeric materials, through a horizontal burning test. In this sense, to perform this test it were used 3 specimens of each sample with dimensions of 125×13×4 mm, which were subjected to a flame at one end of each specimen, during 30 seconds. By performing this test, schematically demonstrated in Fig. 4, it is intended to check the extension of flame propagation during the test. In this context, the results obtained are defined by the extension of the flame propagation.

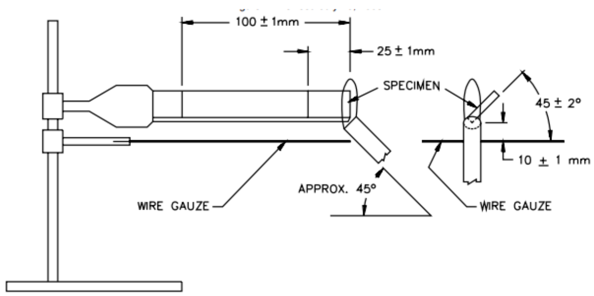

Fig. 4. Scheme of flammability test

III. Results and Discussion

The final composite materials obtained have an aspect like that shown in the Fig. 5, where is demonstrated that it is also possible to obtain materials with different colors using appropriate color pigments.

Fig. 5. Composite materials of slate reinforcing bio-epoxy resin

The summary of results of the several characterization tests performed are presented in Tables II, III and IV, where the samples 1 and 2 corresponds to a different mass fractions used, namely a 50:50 and 70:30 ratios of mineral dust and bio-epoxy resin, respectively. The obtained results were also compared, whenever possible, with the characteristics of virgin slate rock. Moreover, these results are also compared with the Viroc product, Fig. 6. Viroc is a composite material composed by a cementitious matrix and wood particles reinforcements, and is typically used as wall claddings, flooring, ceiling, furniture, among other applications in construction sector.

Fig. 6. Viroc product

Firstly, from Table II, it can be verified the effect of the quantity of different components in the composite materials produced. Sample 1, with 50% of mineral dust waste presents lower density than sample 2, 2.03 g cm^{-3} and 1.82 g cm^{-3}, respectively, and, in turn, these values are lower than the values of virgin slate rock, around 2.7 g cm^{-3}.

In terms of moisture absorption, it were verified low values of this parameter for each sample, around 0.2% – 0.3%. So, it can be concluded that this type of composite materials is almost hydrophobic. This fact is related with the polymeric material and slate's morphology, which is both hydrophobic too, without any trend to absorb moisture. Relatively to a Viroc product, a greatest trend of moisture absorption was clearly noticed, around 15.4%. This highest value, compared with slate materials, it can be justified by the composition and morphology of wood reinforcement. Wood is a natural cellulosic material, and because of that is mainly constituted mainly by cellulose and hemicellulose, which are hydrophilic compounds, and lignin on the surface, which is hydrophobic compound. However, as the wood's morphology is a porous structure, then exists a trend to moisture absorption.

TABLE II
Physical Properties of Composite Materials

Sample	Density (g cm^{-3})	Moisture Absorption (%)
1	1.82	0.3
2	2.03	0.2
Slate Rock	2.70	0.5
Viroc	1.80	15.4

Table III shows the properties obtained in the mechanical tests, namely flexural strength and flexural modulus. Comparing the obtained results of samples 1 and 2 with Viroc product and the virgin slate rock, it is possible to verify an increase of flexural strength from 17.1 MPa and

42.5 MPa to approximately 80 MPa. Moreover, the flexural modulus of sample 2 is bigger than sample 1, which indicates the trend to the better mechanical reinforcement properties with higher quantities of mineral dust. In addition to this, these values are higher than a Viroc's flexural modulus, which has a value of approximately 12.3 GPa.

TABLE III
MECHANICAL PROPERTIES OF COMPOSITE MATERIALS

Sample	Flexural Strength (MPa)	Flexural Modulus (GPa)
1	82.2	16.9
2	78.2	20.3
Slate Rock	42.5	
Viroc	17.1	12.3

Finally, in terms of thermal properties it were presented in Table IV the main results obtained, namely the thermal resistance and the flammability degree verified for each sample.

In terms of thermal resistance, it is verified a decrease of this parameter between the virgin slate rock and the composite materials obtained from 0.035 m^2 K W^{-1} to approximately 0.015 m^2 K W^{-1}. This can be a result of the increased capacity of polymeric materials has to absorb the thermal energy, which promotes the decrease of thermal resistance of the composite materials. Comparing the results of samples 1 and 2 with Viroc product, it can be verified a slight difference, between 0.015 m^2 K W^{-1} to 0.018 m^2 K W^{-1}. Moreover, it is interesting to compare these results with another used construction materials typically used. For instance, it is known that conventional materials such as gypsum block have a thermal resistance of 0.017 m^2 K W^{-1} [3]. Then, it can be concluded that the produced composite materials can be also considered as a good materials to thermal insulation in buildings construction.

Finally, relatively to the flammability results, as can be observed in Table IV, it was obtained the highest classification, an HB rating. This rating means that the samples have a combustion rates lower than 75 mm min^{-1} and the extension of flame propagation was no longer than 100 mm.

TABLE IV
THERMAL PROPERTIES OF COMPOSITE MATERIALS

Sample	Thermal Resistance (m^2 K W^{-1})	Flammability Degree
1	0.016	HB
2	0.013	HB
Slate Rock	0.035	
Viroc	0.018	

IV. CONCLUSIONS

Nowadays, our planet is getting overloaded with buildings, threatening its sustainability. Besides that, the quality of life is also affected with this trend, due to the permanent destruction of large green areas, which are responsible to oxygen production, for buildings construction. Then, the use and recycling of natural materials plays an important role in the innovations trends in several sectors, due the concerns related to sustainability of resources and materials life cycle.

In this context, this study shows that the use of mineral dust from the stone extraction and processing industries can be used to produce composite materials with excellent mechanical and thermal properties, that can be applied in construction sector.

The composite materials obtained allows a reduction of at least 30%, compared to virgin slate rock, which is an extremely important factor, due to the trend to weight reduction clearly verified in several sectors.

In terms mechanical performance, it was verified that the polymeric composite materials reinforced by mineral dust waste allows an increase in flexural strength of at least 90%, comparing with virgin slate rock, and 350%, comparing with Viroc product. Moreover, it was also demonstrated a trend for the increase of slate dust waste in composite materials induces better flexural modulus.

Thermal insulation tests of the composite materials produced showed a decrease of more than 100% of thermal resistance, compared to virgin slate rock. This conclusion can be explained by the higher energy absorption capacity of the polymeric material used, compared with the slate rock. However, comparing with another similar products actually used in construction sector, such as Viroc and gypsum block, it were verified a similar values.

On the other hand, with these new materials, it can be possible a wide range of shapes, which is also an important trend.

Thus, from this study, it can be concluded that the recycling and recovery of mineral waste, such as slate waste, has a huge application potential in several areas, like as construction.

ACKNOWLEDGMENT

The authors gratefully acknowledge to project *"Fibrenamics Green - Platform for the development of innovative waste-based products"*, code NORTE-01-0246-FEDER-000008, which is co-financed by the European Union, through the European Regional Development Fund (ERDF) under the NORTE 2020 - North Portugal Regional Operational Program 2014–2020.

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