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ScienceDirect
Procedia Engineering 10 (2011) 3214–3219
Engineering Procedia

ICM11

Cork composites and their role in sustainable development

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Abstract

With the current challenges that the industrial world faces regarding the unavoidable environmental impact of manufacturing goods, companies have been turning to sustainable design in order to reduce this impact and to minimize the damage to the environment while at the same time reaping the marketing bonus that is the claim of a greener product.
This reduction of environmental impact is being done at multiple levels and especially at the design stage and one of the ways taken by companies to reduce this impact is to replace fuel-based materials such as polymers with natural materials.
But in order for this replacement to take place, engineers and designers need to know the behavior of these materials.
With that idea a set of mechanical tests and studies, namely bending and compression tests, have been performed on cork composites. Those composites were chosen for its importance to the Portuguese economy and its peculiar growth cycle and harvesting techniques, in order to ascertain the mechanical properties of cork composites and how it stands against polymers.

Selection and peer-review under responsibility of ICM11

Keywords: Sustainability design; Cork composites; Experimental tests; Environmental impact.

1. Introduction

Possibly one of the most important events in the history of mankind, the industrial revolution almost completely transformed the social and economical landscape of the world, with Gross Domestic Product (GDP) per capita increasing 10fold and population increasing 6-fold [1]. From manufactured goods at a lower price, the invention of the internal combustion engine, the creation of transportation networks and the development of capitalism the impact was felt in all aspects of the society. Unfortunately this revolution had a price. The increase in production was achieved from what was considered infinite resources, and those resources turned out to be anything but infinite.

The first call of attention was made by Thomas Malthus in his book "An Essay on the Principle of Population" [2] where he warned that the potential for growth of the human population is vastly superior to nature's ability to

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Selection and peer-review under responsibility of ICM11 doi:10.1016/j.proeng.2011.04.531

sustain it, with the inevitable outcome of strife to all involved. In it laid the foundations of Malthusianism where the geometric growth of a population would at some point overtake the linear growth of the resources.

This idea has been expanded beyond Malthus original scope but retains the same impact. The growth of population, coupled with the basic tenets of the economic model used since the industrial revolution (one of continuous economic growth), lead to a geometric growth on the need of resources, which at some point will (or have depending on the point of view), overtake earths ability to supply them. This model can also be applied to other effects of the population growth.

2. Sustainable Development

Environmental issues remained largely under the radar for the next 150 years resurfacing with the Club of Rome, and its publishing of the book “The limits of growth” [3]. This book, commissioned by the Club of Rome to the Massachusetts Institute of Technology (MIT), utilized a computer model (world 3) to analyse the evolution of the world through the interplay of five systems comprising a total of 8 variables. Several scenarios were run including a standard run, *i.e.*, a run where the observed trends in the world would be maintained throughout [4].

The results were dramatic. In the standard run, the model predicted a full collapse of the economy in the middle of the 21st century, due to resource depletion, pollution, and population growth.

The United Nations, trailing in the wake of the book, created the World Commission on Environment and Development (WCED) in 1983 that published in 1987 “Our common Future” otherwise known as the Brundtland Report [5], where the word Sustainable development is first coined. But what is exactly sustainable development? According to the report "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

In other words the ability to produce, today, whatever goods necessary without endangering the ability of doing the same in the future, avoiding the collapse predicted by “The Limits of growth”.

How to do it has been the concerns of academics and companies for the past twenty years with numeral solutions proposed [6]. All of them take into account that there is always an environmental impact inherent to manufacturing a good [7].

3. The role of natural materials

One of the ways to achieve sustainable development is to substitute non-renewable resources or resources nearing depletion due to overconsumption, with renewable ones [8]. One way to do so is to turn to natural materials such as vegetable fibers, natural resins and other materials such as chitin that can combine the minimal environmental impact in harvesting and producing with sufficient mechanical performance to replace some non-renewable materials currently in use. These materials are being studied and promise to be of great importance in the future, combining good environmental performance low environmental impact.

One of such materials has been studied quite thoroughly in the past decade, and, due to its unusual combination of characteristics seems a promising candidate. Cork based composites are extracted from the Cork Oak tree (Quercus Suber L.).

3.1. Cork

Cork is extracted from the cork oak tree (Quercus Suber L.), one of the most prolific trees in the Mediterranean Ecosystem. It’s forests are valued for its biodiversity [9], Livestock feeding [10], CO_2 Retention rates [11, 12] and economical value. The defining feature of the Cork oak is the production of its outer layer, a technically waterproof viscoelastic material known as cork.

Cork has been used for millennia in the production of bottle stoppers, and has a place in the annals of science, since it was a cork cell that Robert Hooke studied in his microscope, and from which the name “cell” arises. As a material it has an unusual array of properties such as high coefficient of friction, heat resistance, sound proofing, among others, have made it an object of study with multiple publications on the subject [13-15].

Economically, cork has a significant importance on the Portuguese GDP, with a sales volume of 698,3 million Euros, representing 0,7 of the Portuguese GDP and 2,2% of the total exports in 2009 [16]. Environmentally there have not been many studies made about cork. The main assessment made was a study made by PriceWaterhouseCoopers/Ecobilan [12] which studied the amount of CO_2 released during the production of bottle stoppers. This study however did not take into account the recyclability potential of the materials, which could improve the environmental performance of Cork since the potential recyclability of cork can be as high as 100% and the recycled products lose little to no characteristics, see Table 1.

Table 1. CO_2 Released during the production of 1000 stoppers

Material	CO_2 per 1000 stoppers [g]
Aluminium	37.161
Plastic	14.716
Cork	1.437

Cork composites, like the ones studied in this work, are made from the leftovers of bottle stoppers production. These boards are grinded to specific granule size and mixed with a specific resin. Then they are pressed and allowed to cure in order to agglomerate the granules into a compact shape, with pressing force, cure time and granules size mix the main parameters in establishing the mechanical properties of a specific composite.

3.2. Experimental procedure and specimens

Although the primary analysis shows that cork might be a good eco-material, such environmental properties are meaningless if the mechanical behavior of cork composites is unsatisfactory. To evaluate that purpose, it was decided to perform some mechanical tests to ascertain the mechanical behavior of cork composites. A systematic approach was defined starting with tests to determine what could be the main avenues of work for cork composites, so that then more advanced testing could be made, more focused on the strengths of the cork composites.

To that end the first batch of tests consisted of compression and bending tests using the ASTM C-365 and ASTM D-790 test procedures. For specimens, two different cork composites were chosen, namely Amorim Cork Composites CORECORK® references NL10 (Density 120 Kg/m^3) and NL20 (Density 200 Kg/m^3).

4. Results and Discussion

4.1. Compression tests

Compression tests were carried out following ASTM C-365. The tests were performed in testing machine with a 10kN loading cell, a crosshead speed of 0,5 mm/min and with cross sectional areas of 625 mm^2 and 2500 mm^2. Twelve tests were performed for each specimen of which 10 tests were accepted for both specimens, see Table 2 and Fig.(s) 1 and 2.

Table 2: Test results from compression tests

ASTM C -365	NL 10	NL 20
Yield Stress [MPa]	0,215	0,564
Compressive Modulus [MPa]	5,399	9,798
StDev (Compressive Modulus) [MPa]	0,922	0,570

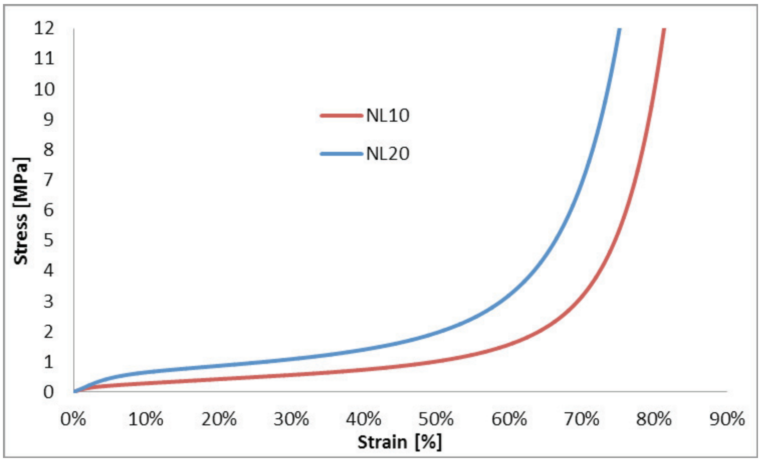

Fig. 1 ASTM C-365 Stress vs Strain curves

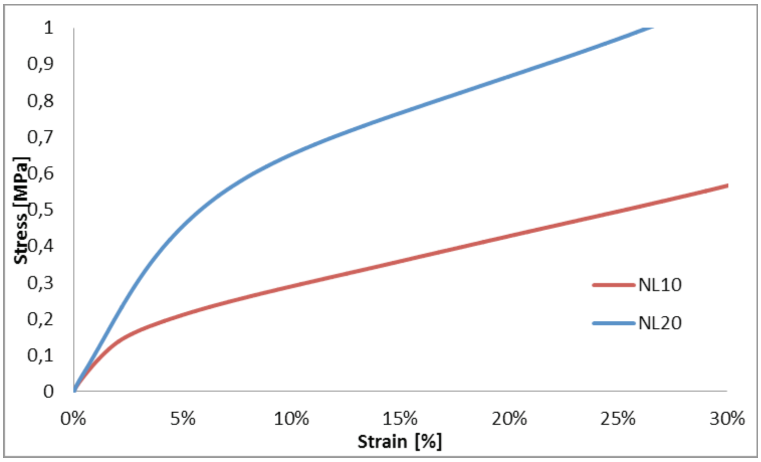

Fig. 2 ASTM C-365 Stress vs Strain Curves, zoomed to the Elastic portion of the curve

The results of the tests show values fractionally larger than those supplied by Amorim Cork Composites. One item that draws attention is the value of the standard deviation for reference NL10 with almost a 20% difference. This is a value that may be considered too high for an engineering material. Preliminary analysis seems to indicate that the fluctuation of the values is due to the low density of the material, coupled with the manufacturing process, *i.e.*, the area of contact between adjacent granules and the resin is less and less homogenous if smaller and smaller cross section area specimens are used. This is being tested by re-running the tests with a higher cross sectional area (10 000mm^2).

The Compression Modulus value is smaller for Reference NL10 than it is for reference NL20, a result that was expected since the lower density of NL10 means less contact area between granules and resin, lowering the amount of loads the specimen can reach.

4.2. Bending tests

The other test performed was the ASTM D-790 Bending test. The experimental test carried out was a 3 point bending test. It was performed in a testing machine with a 10kN Loading cell, a cross head speed of 4,7 mm/min with the following specimen dimensions, see Table 3.

Table 3: ASTM D 790 Specimen Dimensions

ASTM D 790	Dimensions [mm]
Depth	11
Width	44
Length	211,2
Support Span	176

Seven tests were performed for each specimen, of which 5 were accepted for reference NL10 and 7 for the reference NL20.The results of the tests are presented in Table 4 and Figure 3.

Table 4: ASTM D790 Test Results

ASTM D 790	NL 10	NL 20
Flexural Strength [MPa]	0,61	1,24
Flexural Modulus[MPa]	20,25	39,1
Standard deviation [MPa]	0,98	0,86

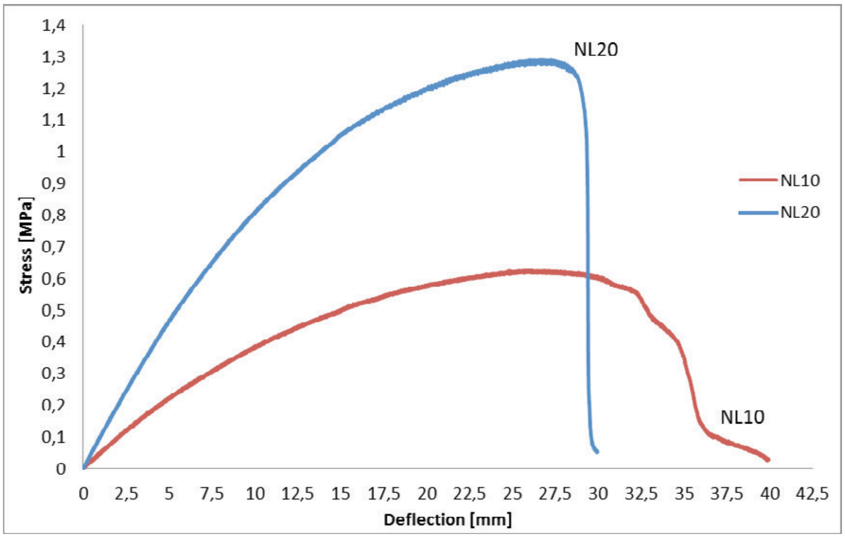

Fig. 3 ASTM D-790 Stress Deflection Curve, Maximum Stress values at half span.

Observed in all test was that the crack propagation was between granules, meaning that the possible cause of failure is debonding between granules, either in the interface resin/cork, or due to failure of the resin itself.

NL10 specimens showed in 3 of the tests premature cracks, again possibly due to the contact area between granules being smaller and thus the cross section being actually smaller than the one measured, and the smaller contact area allows for less resin to "hold" the composite together. The NL20 specimens due of their higher density have more contact area bonded by the resin and thus show a superior ability to handle higher loads.

Cork composites values, although better than cork are still somewhat lower than PVC foams for a similar density, a fact that may impact negatively on its marketability.

5. Conclusions

The adoption of natural materials for sustainable development begins with the full characterization of their mechanical behavior in order to determine if such a material is able to handle the design parameters of any new design. The tests show that cork composites outperform their origin material and at a lower price. Their mechanical behavior precludes them from any sort of structural role, but given its density there is a future ahead for cork composites as a core material in a sandwich structure.

Acknowledgements

The authors wish to acknowledge Amorim Cork Composites, Mar Kayaks and FCT/MCTES, EDAM/MIT-Portugal.

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