Book Chapter

Perspectives of Using Eucalyptus Bark Fibre in Concrete

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Abstract

Concrete is a material with high compressive strength, but predisposed to shrinkage cracking, rapid cracks propagation, and brittle failures. The incorporation of fibre is an acceptable solution to reduce these limitations. However, high cost and energy consumption related to man-made fibres have placed natural fibres as an attractive sustainable alternative, especially considering that different natural fibres are industrial waste. Still, natural fibres can produce an important reduction of concrete strength, being this property fundamental for the massive use of concrete. Hence, an essential step to define potential applications of concrete with a natural fibre is to evaluate the effects of that fibre in traditional concrete mechanical properties as compressive and flexural strength. In this way, that evaluation is the first objective of the present book chapter, and, based on those results and fibre properties, to define potential applications of concrete with *Eucalyptus globulus* bark fibre. In effect, an experimental program was developed in such a way that reduces the results uncertainties and increases the power of decision regarding the percentage and fibre conditions of the samples. In addition, a comparison of mechanical properties of natural fibres, and their concrete applications, is included as well. The results indicate that, unlike other natural fibres, the traditional mechanical properties have a slight reduction and acceptable workability. This fact is more evident in the samples with 0.50% fibre with respect to the weight of cement. Bases on these results, and the use of other fibres in concrete, is possible to conclude that incorporating *Eucalyptus globulus* bark fibres emerges as an eco-friendly building alternative for micro-cracking control and improving concrete ductility.

Keywords

Concrete Applications; *Eucalyptus globulus*; Natural Fibre; Mechanical Properties; Reinforced Concrete; Sustainability

1. Introduction
1.1 Fibre Reinforced Concrete

Globally, concrete is one of the most used materials in the construction industry, with an estimating production of 30 billion tons per year [1]. Despite being a material known for its high compressive strength [2], the concrete material is predisposed to shrinkage cracking, rapid cracks propagation, and brittle failures [3,4]. In this context, the addition of fibres in the concrete mixture has proven to be an acceptable solution to minimize these limitations [5–7]. In effect, fibres improve the post-cracking behaviour and the residual strength of concrete, which is important for the overall performance of concrete members under monotonic and cyclic loading [8–10]. Fibres are a promising non-conventional reinforcement in concrete elements because they alter the brittle failures to ductile (pseudo-ductile) ones, improving the deformation capability, reducing cracking and presenting higher energy dissipation regarding to the non-fibrous elements [11–14]. Fibres can also contribute to minimize the corrosion problems in concrete structures, because fibres limit the formation and cracking increment, and they can replace part of the steel reinforcement [10,15].

The fibres consist of thin and short filaments that are randomly distributed throughout the structure [16,17]. According to their composition they are classified as steel, glass, synthetic or natural fibres [18]. However, the vulnerability of steel to corrosion and the high cost and energy in the manufacture of synthetic fibres have placed natural fibres as an attractive reinforcement alternative [19]. In addition, man-made fibres are non-biodegradable, and when they are disposed of in landfills, they can cause pollution by releasing heavy metals and other pollutants into the ground water as well as in the soil [20,21].

Natural fibres as reinforcement material have been used in construction since the early 19th century [22]. Between the applications of concrete with natural fibres reinforcement is possible to find the construction of pipes, silos, slabs on grade, airports and pavements, tunnelling, rock stability, shotcrete, and others [23–25].

Compared to man-made fibres (steel, glass and synthetic), natural fibres are less expensive, locally abundant (sometimes as a waste), renewable, lightweight and biodegradable [26–30]. Moreover, natural fibres have very low embodied energy [31], i.e., sum total of the energy used at each step of the process needed to create a particular finished product. The carbon footprints as well as the embodied energy of natural fibres are very low as compared to artificial ones [32]. Furthermore, the health and safety concerns during their handling, processing, and mixing are less [33]. Therefore, from a sustainable perspective, natural fibres are postulated as a promising reinforcement material for concrete using natural assets and with a non-hazardous impact on the environment [33–35]. This is especially relevant in the construction industry, which is responsible for a large amount of non-renewable resources and (only in Europe) of 30% of the emission of carbon dioxide gases [15].

However, the incorporation of natural fibre can produce a significant reduction in the concrete compressive strength. There is more reduction as the amount of fibres increase [36]. For example, Yalley and Kwan [37] studied the mechanical performance of coconut fibre reinforced concrete with 0.25%, 0.50% and 0.75% with respect to the weight of the cement. Compared to the control samples (without fibre), the results show a decrease in compressive strength between 11% and 33%.

Similarly, Zakaria et al. [35] report that incorporating 0.75%, 1.75%, and 3.52% of jute fibre, with respect to the weight of cement, reduces the compression strength between approximately 6% and 35%. Moreover, Okeola et al. [38] mentioned that adding sisal fibre in 0.5%, 1.0%, 1.5%, and 2.0% with respect to the weight of cement, causes a compressive strength reduction by 4.22%, 11.54%, 18.18%, and 25.30%, respectively. Finally, the study performed by Yursa et al. [39] shows that the addition of concrete with bamboo fibres in 0.5%, 1.0%, and 1.5% of the weight of cement decrease the compressive strength in 1.67%, 5.44%, and 12.00%, respectively.

As concrete strength, especially compressive strength, is a fundamental characteristic related with the massive use of this material, the incorporation of waste into the concrete, requires a strength evaluation of the concrete-waste composite. In fact, that incorporation can generate different technical benefits, but if the strength of the concrete-waste composite is significantly less than the reference concrete, the practical possibilities to be massively used in different concrete applications can be very limited. However, from a sustainable point of view, it is important to produce a composite concrete-waste that effectively has practical possibilities to be applied. For that reason, the strength evaluation of that composite is fundamental. This is even more evident when the waste is natural fibres because different authors report a reduction of the compressive strength as the amount of fibres increases [35-39]. Then, being the amount of fibres to incorporate in the concrete limited to a small quantity, a significant reuse of waste fibres will be related with the massive use of concrete, which will depend of the strength of the concrete-fibre composite. That is an important reason why several studies have focused on evaluating the performance of mixes with different natural fibre dosages. The final goal of that process is to determine optimal proportions to be incorporated into the concrete [40-43]. Those proportions will be related, between other factors, with the particular fibre under study, the treatment applied during its incorporation and the uniformity of volume distribution of the fibre in the mix [29,44].

1.2 Natural Fibre in Concrete: The Case of Eucalyptus Globulus Bark Fibres

In Chile, E. globulus has a relevant role as one of the most used tree species in the forestry industry [45,46]. In particular, at the Biobio region, which concentrates forest plantations, 4.2 billion of wood are consumed per year [46]. This generates bark corresponding to 9.2% of the total volume of the tree [47] and represents approximately 386 thousand m3 of annual bark. This is not an isolated case. In fact, Eucalyptus plantations cover large areas around the world (>20 million hectares) in countries, such as Australia, Spain, Portugal, Kenya, Brazil, Uruguay, and Chile [48]. Therefore, the disposal and reuse of Eucalyptus bark is a problem in different countries and regions. In effect, the bark is the external protection of the tree, and it needs to be extracted before the wood can be commercially used. In this way, the bark is an industrial waste. In particular, at the Biobio region in Chile, part of the E. globulus bark waste generated is used to produce energy. However, compared to other biomass products, the process is inefficient due to its fibrous structure, low heating value and higher ash content [49]. Therefore, it is necessary to develop alternatives that contribute to the reuse of waste.

Although there have been several studies related to concrete reinforcement with natural fibres of different origins [38,40-43,50,51], to the best of the authors' knowledge, there is a lack of research considering fibres from the bark of the species E. globulus, and its impact on concrete performance. This is an important fact, because bark is distinctive of a tree, and even they are different between Eucalyptus species. Actually, bark is an important element of tree identification [52]. Furthermore, as bark protects the tree from the environment where it is located, the bark characteristics are geo-dependent as well.

Geo-dependency is fundamental when dealing with waste materials and concrete, especially because the alternatives of solutions must be practical and possible to apply. This, from a sustainable perspective, will allow to effectively reuse the industrial waste. Actually, geo-dependency is one of the characteristics of the concrete material that make it so popular, as it is possible to use local raw materials.

This book chapter is based on the article "Evaluation of Mechanical Properties of Concrete Reinforced with Eucalyptus globulus Bark Fibres" by Mansilla et al. [53]. The main results obtained are presented as a summary. Additionally, based on the results of mechanical strength, and comparisons with other natural fibres, prospects for concrete applications with E. globulus bark fibres are analysed.

2. Methodology

2.1 Methodological Approach

Based on Mansilla et al. [53], sections 2.2 and 2.3.1 present the materials and methods for the evaluation of the mechanical properties of concrete reinforced with Eucalyptus Globulus bark fibre. Section 2.3.2 presents a comparison of relevant properties of E. Globlulus bark fibre with other natural fibres used in concrete applications.

2.2 Materials for the Evaluation of the Mechanical Properties

2.2.1 Cement

Two commercial brands of cement available in the local market were used in this research: Bío Bío Especial (C1) and Polpaico Especial (C2). This choice was based in the necessity of proposing practical and sustainable alternatives for the effective use of ELT rubber. According to the standard NCh 148 [54], based on ASTM C150/C150M-20 [55], C1 and C2 cements were classified as standard grade Portland pozzolanic cement.

2.2.2 Aggregates

Table 1 presents the properties of the fine and coarse aggregate (20 mm maximum size) used in the samples. Both aggregates satisfy the minimum requirements for the production of mortars and concrete [56].

Table 1: Physical properties of fine and coarse aggregates.

Physical Properties	Fine Aggregate	Coarse Aggregate
Loose bulk density (kg/m^3)	1.57	1.49
Bulk density consolidated (kg/m^3)	1.66	1.63
Relative density dry (kg/m^3)	2.66	2.67
Absorption (%)	2.05	1.05
Fineness Modulus	3.12	6.67
Organic Impurities	No	-

2.2.3 Eucalyptus Globulus Bark Fibre

The E. globulus bark fibres were provided by the Unidad de Desarrollo Tecnológico, UDT (Technological Development Unit) of the Universidad de Concepción, Chile (Figure 1). The fibre is characterized by having a light brown colour (Figure 1), absorption of 350%, length between 10 mm and 20 mm, and 2 mm average thickness. The chemical composition is presented in Table 2. Previously, the fibres were screened in order to use only material retained in 3/8” sieve.

Figure 1: *Eucalyptus globulus* bark fibre.

Table 2: Chemical composition of *E. globulus* bark fibre.

Component	**% Dry Solid Base**
Ethanol/Water Extractives	7.43 ± 0.03
Cellulose	49.91 ± 2.56
Hemicellulose	18.12 ± 4.16
Klason Lignin	17.60 ± 0.49
Ash	7.62 ± 0.32
Absorption (%)	350

2.3 Method

2.3.1 Experimental Program

In order to increase the information possible to obtain from the samples behaviour, the experimental program was divided into three consecutive stages (Figure 2). This strategy was chosen to narrow the range of study based on the results obtained in the previous phase. In this way, stage 1 considers the evaluation with two cements and high percentages of bark fibre (2% and 5%). According to the results obtained in stage 1, the cement with the best performance is chosen for the next phases. In a similar way, decisions are taken regarding to the percentage of bark fibre based on the results of the previous phases. Then, at stage 3, only the percentage of fibre with the best results at stage 2 is evaluated.

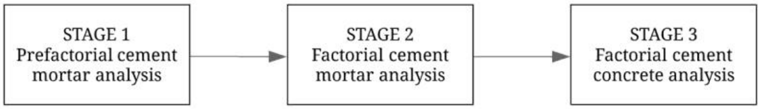

Figure 2: Experimental program with three consecutive stages.

The present chapter focuses on stages 2 and 3. This is because promising results were obtained in these stages on samples of mortars and concretes reinforced with E. globulus fibres. For more details on stage 1 see Mansilla et al. [53].

Figure 3 presents the details of the second stage. This phase consists in a factorial analysis of cement mortars. The tests were performed on specimens with dimensions of 40 × 40 × 160 mm according to the Réunion Internationale des Laboratoires et Experts des Matériaux, systèmes de construction et ouvrages (RILEM) [57]. The samples were made cement 1, estimating a compressive strength of 41 MPa and slump between 3 cm and 8 cm. These target values were chosen based on the importance of developing practical alternatives towards effectively reusing industrial waste.

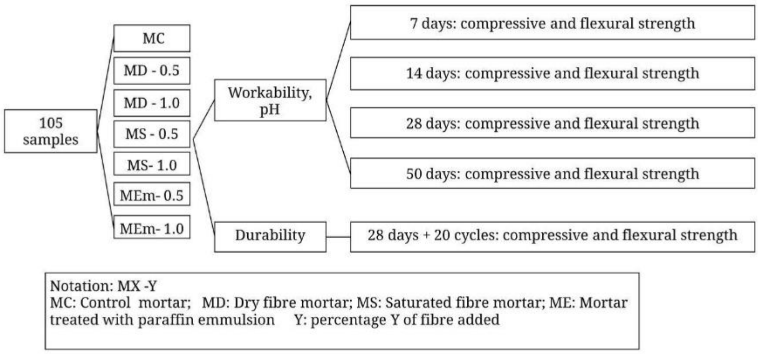

Figure 3: Work plan description of stage 2.

The fibre was added in proportions of 0% (control sample), 0.5%, and 1.0% in relation to the weight of cement. The cement mortar mixes were designed following the design principles presented by the Chilean Road Agency [56] and Egaña [58], for more details see Mansilla et al. [53].

In addition, the fibre was added in a dry, saturated state, and treated with a paraffinic emulsion composed of 10% paraffin and 90% water. This last case was included to evaluate the potential effects on the fibres durability. In effect, the modification of the fibre surfaces with physical or chemical agents is a mitigation strategy to protect them against the potential degradation caused by the alkaline environment of the cementitious matrix.

In fresh state, the consistency of the cement mortars samples was evaluated by means of the reduced Abrams cone slump method, according to NCh 2257/3 [59] and the pH values recorded with a Hanna pH-meter model pH21. This allows monitoring the alkalinity levels of the cementitious matrix while evaluating the performance of the fibre reinforced mortars. The compressive and flexural strength of the samples was evaluated, at 7, 14, 28 and 50 days according to ASTM C 270 [60], using multi-test equipment SERCOMP 7 controls.

Additionally, a preliminary evaluation of the durability of the fibres in the cementitious matrix was made through accelerated ageing process. However, the results of this evaluation are not presented in this chapter. This is because no significant changes in the performance of the mechanical properties of the samples were observed. More information on this test can be found in Mansilla et al. [53].

Figure 4 presents the details of the third stage. This phase consists of the factorial analysis of concrete cubic samples (200 mm) and beam samples (150 × 150 × 530 mm). Cement 1 was used in the preparation, estimating a compressive strength of 43.5 MPa and slump between 5 and 7.5 cm. The fibres were incorporated in a dry and saturated state. The fibre dosages considered were 0% (control sample) and 0.5% in relation to cement weight.

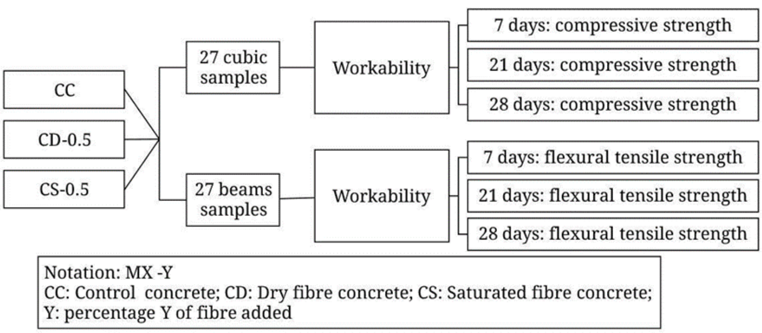

Figure 4: Work plan description stage 3.

The concrete mixes evaluated in stage 3 were designed based on the American Concrete Institute (ACI) method [61], for more details see Mansilla et al. [53]. In the preparation, the consistency of all samples was evaluated by means of the Abrams cone slump method according to ASTM C143/C143M [62]. At this stage, docility, compressive and flexural strength were evaluated at ages 7, 21, and 28 days, according to ASTM C94/C94M [63].

2.3.2 Analysis of Potential Applications of Concrete with E. Globulus Bark Fibres

The investigation of potential concrete applications with E. Globulus bark fibres is based on the results obtained in the experimental programme and the comparison of the mechanical properties of this fibre with other natural fibres considered appropriate for concrete reinforcement (Table 3).

Table 3: Comparison of mechanical properties of E. globulus bark fibre with other natural fibres

	Mechanical properties		
Fibre	Tensile tress (MPa)	Elasticity modulus (GPa)	Reference
Eucalyptus Globulus	224±109	2.29±1.52	Fuentealba et al. [64]
Coconut	15-220	3.1-3.5	Agopyan [65], Rehsi [66], Poongodi [67]
Banana	125-180	2.9-3.3	Poongodi [67]
Rice straw	74.6	-	Qamar et al. [68]
Pig hair	92.2±41.7	-	Araya-Letelier [69]
Bamboo	166-291	-	Yursa et al. [39]
Larch	232±77	9.4±3.3	Beltra [70]
Spruce	169±36	7.7±3.7	Beltra [70]
Pine	124±75	4.5±2.6	Beltra [70]
Sisal	58.16	-	Ramakrishna [71]
Jute	50.89	-	Ramakrishna [71]
Hibiscus Cannebinus (Indian hemp)	76.04	-	Ramakrishna [71]

The values of the mechanical properties of E. Globulus bark fibres are within the range of various natural fibres accepted as adequate for incorporation in concrete. Therefore, although further study with E. Globulus bark fibres is still necessary, at the present state potential applications of concrete with these fibres are possible to identify, comparing the behaviour reported for different authors when other natural fibres are incorporated in concrete, and those fibres have similar mechanical properties than E. Globulus bark fibres.

3. Results

3.1 Stage 2: Cement Mortar Factorial

3.1.1 Fresh State Behaviour

Table 4 presents the slump, by means of the reduced Abrams cone [59], and the pH values.

Table 4: Cement mortal factorial, consistency, and pH of the mixes.

Mortar mix	Slump (cm)	pH Values
MC	4.1	12.9
MD-0.5	3.0	12.8
MD-1.0	3.0	12.9
MS-0.5	3.0	12.7
MS-1.0	3.0	12.8
MEm-0.5	3.5	12.4
MEm-1.0	3.0	12.0

The results indicate that for all cases the inclusion of fibre slightly reduces the mix docility. However, the 1 cm slump reduction is relatively constant and cannot be necessarily attributed to an increment or state of the added fibre [72].

When comparing the pH measurements with the control sample, it is observed that in all cases the pH decreases. However, these reductions are small being the standard deviation 0.67. Hence, it is possible to conclude that no significant changes in the concrete alkalinity are produced between samples with and without fibres.

3.1.2 Compressive Strength

Figure 5 shows the average compressive strength of the tested samples at the factorial phase.

Figure 5 shows that for all ages, the greatest strength was obtained with the control sample. Regarding fibre samples, the best results at 28 days are obtained for the MS-0.5 sample, obtaining 88% of the control sample strength. This result is followed by the MD-0.5 sample with 86%. The lowest result is the MEm-1 sample with 77%.

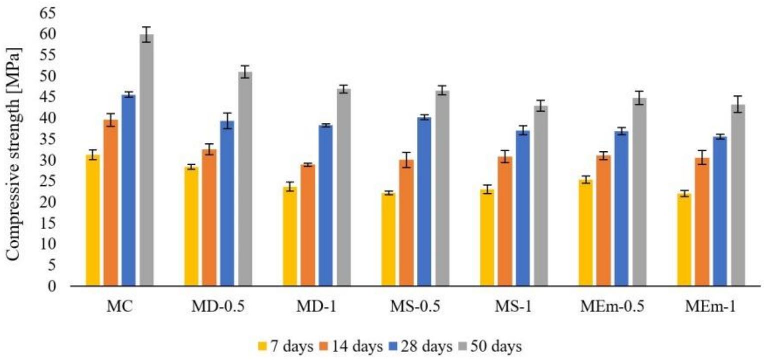

Figure 5: Cement mortar factorial results, compressive strength.

At 50 days, the best performance is presented by the MD-0.5 sample, which reaches 85% of the control sample strength. The MS-1 and MEm-1 samples show the lowest results with 72%.

Comparing the results of samples with incorporated fibre, the addition of 0.5% fibre gives better compression strength results than 1%. This fact is maintained regardless of the fibre treatment. The results obtained can be attributed to the fact that a low amount of fibres reduces the possibility of fibre concentration (Figure 6) and production of weak spots [35].

Figure 6: Cement mortar samples with 0.5% E. globulus bark fibres.

3.1.3 Flexural Strength

Figure 7 shows the average flexural strength at ages 7, 14, 28, and 50 days. At 28 days, the fibre samples with the best performance are MD-0.5 and MS-1. They reached 90% of the control sample strength. The lowest results were obtained by MEm-1, with 73% of the control sample strength.

At 50 days, the fibre sample with the best performance was the MS-1 with 94% of the control sample strength. This result is slightly higher than the ones obtained by samples MD-0.5 and MD-1 with 93% and MS-0.5 with 92% of the control sample strength respectively. Again, the samples with fibres treated with paraffin emulsion presented the lowest strength regarding to the control samples, with 73% and 80% for MEm-1 and MEm-0.5, respectively.

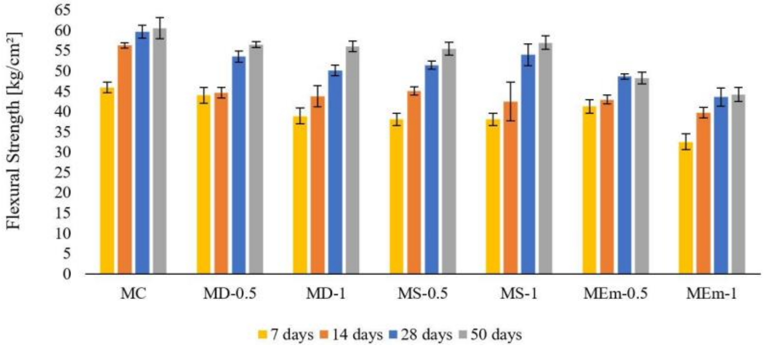

Figure 7: Cement mortar factorial results, flexural strength.

The flexural strength reached by samples with 0.5% and 1.0% is very close to the control samples, especially for the cases highlighted before. Furthermore, the results at 50 days indicate that the fibre samples keep winning strength reducing the gap with the control samples. This fact suggests that the samples with bark fibre can have a later strength development that is worthy to further investigations.

Similar to what was expressed in Section 3.1.2, the results obtained can be attributed to the low amount of fibres, which reduces the possibility of fibre concentration (Figure 6) and production of weak spots [35].

There are no significant differences in adding the fibres in dry or saturated state. Therefore, it is not essential to dry the fibre before adding it to the mixture. With respect to the fibres treated with paraffin emulsion, similar to the compressive behaviour, there are no strength advantages related with their application.

3.2 Stage 3: Concrete Factorial

3.2.1 Fresh State Behaviour

Table 5 shows the slump recorded using the Abrams cone method [62].

Table 5: Concrete factorial results, docility.

Concrete mix	Slump (cm)
CC	7.0
CD-0,5	7.0
CS-0,5	8.0

The CS-0.5 mix shows a slight increase in its docility. However, this value is within the range of permissible variation [63,73], and thus it is not necessarily associated with the added fibre.

In contrast, the incorporation of dry fibre did not show variation with respect to the control sample.

3.2.2 Compressive Strength

The concrete compressive strength results are presented in Figure 8.

At all ages, the greatest strength is obtained by the control sample. However, the CD-0.5 sample has slightly lower values. In fact, after 28 days its strength only differs 0.98 MPa of the control sample, being 0.82 MPa the standard error. Hence, the difference is very close to the error. The CS-0.5 sample reached a 28-day difference of 1.8 MPa respect to the control sample strength.

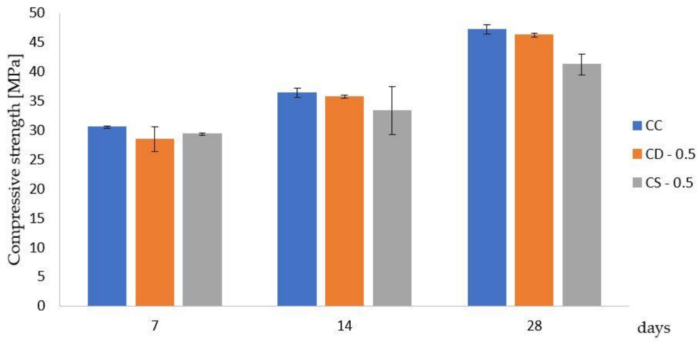

Figure 8: Concrete factorial results, compressive strength.

The good results obtained can be explained in a similar way than the results of stage 2 described in Section 3.1.2.

Other researchers have also found their best compressive strength results with lower amount of natural fibres [35-38]. In general, the compressive strength decreases more, for similar percentage of fibre, than the results presented in this section. Actually, the compressive strength reductions of those investigations varies between 4.22% and 11.00% for 0.50% fibre reinforcement with respect to the weight of cement [35,37,38]. In the present investigation the best result differs only 2.00% of the control sample, being the difference very close to the standard error with a coefficient of variation 1.73%. This is a very promising result towards developing practical alternatives for effectively reusing the bark fibres of Eucalyptus globulus species, considering that concrete strength, and particularly compressive strength, is related with the massive use of concrete and different numerous of concrete applications.

3.2.3 Flexural Strength

Figure 9 presents the results of the concrete flexural strength.

At 28 days, the best results are obtained by the control sample. It is observed that the CS-0.5 sample has a 0.20 MPa reduction, being 0.22 MPa the standard error, i.e., the difference cannot be considered significant. The CD-0.5 sample shows a reduction of 0.7 MPa (13%).

The good results obtained can be explained in a similar way than the results of stage 2 described in Section 3.1.3.

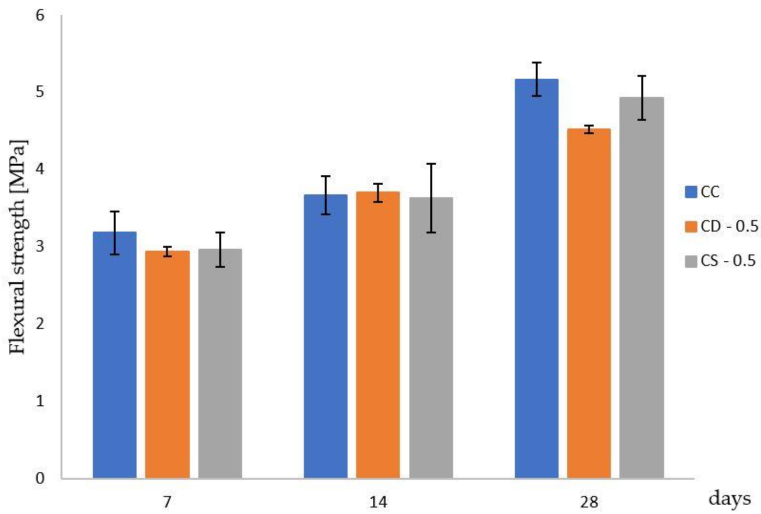

Figure 9: Concrete factorial results, flexural strength.

3.3 Potential Applications of Concrete with Eucalyptus Globulus Bark Fibres

3.3.1 Bases of Potential Applications

The results presented indicate that mortars and concretes with 0.5% and 1.0% of bark fibre of E. Globulus develop an acceptable behaviour in terms of the obtained strength, although lower when compared with samples without fibre. Nevertheless, when comparing the results with the ones obtained with other types of vegetable fibres [35,37,38], it is observed that the strength reduction is low.

This fact is relevant to the potential applications of E. Globulus bark reinforced concrete. In effect, although fibres can improve different engineering properties of the concrete material, if the strength of the composite concrete-fibre is significantly reduced regarding to the reference concrete, the possibilities to effectively reuse the waste are very limited. This is due to the fact that concrete strength is related with the massive use of this material in numerous different applications. Then, as the percentage of natural fibres possible to incorporate in the concrete material is low, the massiveness factor is fundamental to reuse significant amounts of waste natural fibres. In this respect, the present phase of the investigation has demonstrated that the incorporation of E. globulus bark fibre does not reduce significantly the compressive and flexural strength of the concrete material.

The promising results obtained in the phase of the investigation can contribute to reduce the waste material, for instance, at the Chilean forest industry, especially considering the massive use of concrete in Chile. In fact, it is estimated that over 70% of the Chilean constructions are built with this material [74]. Furthermore, concrete is the material of greater volume used by man and it is very difficult to replace in numerous infrastructure applications [75].

Considering the mechanical behaviour observed experimentally and based on comparisons of the properties of E. Globulus fibres with other natural fibres proposed in different concrete applications, the following potential applications with incorporation of E. Globulus fibres are visualised.

3.3.2 Incorporation of E. Globulus Fibres to Control Concrete Micro-Cracking

In order to prevent corrosion deterioration, it is essential to reduce the formation and propagation of micro-cracks generated by the concrete shrinkage phenomena at early age [76-78]. An alternative to mitigate the number, size and propagation of micro-cracks is to incorporate fibres into the concrete [5,7]. For instance, Araya-Letelier et al. [69] demonstrated the possibility of limiting the number and size of micro-cracks in concrete using Chilean cements and natural fibres with a tensile strength 54% lower than the one of E. Globulus bark fibres. Moreover, the investigation of Yalley and Kwan [37] reports that coconut fibres, with an average tensile strength of 88.5 MPa, can enhance the ability of concrete to resist cracking. This represents an improvement in crack control using fibres with 61% lower tensile strength than E. Globulus bark fibres.

The control of micro-cracks in concrete is particularly attractive in regions with aggressive environments for reinforcement corrosion, such as coastal areas, where chloride attack and other external agents are severe. In this context, the incorporation of E. Globulus in the cementitious matrix could contribute to control the concrete micro-cracking with a significant reduction of maintenance interventions during the lifetime of the structure.

3.3.3 Incorporation of E. globulus Fibres to Improve the Concrete and Mortar Ductility

One of the advantages of fibre reinforcement is to impart additional energy-absorbing capability by transferring a brittle material into a pseudoductile one [79]. This characteristic makes natural fibres an attractive alternative of reinforcement for mortars and concretes. In fact, Ayala-Leiter [69] mentions that mortars with natural fibres can show a similar improvement in impact resistance compared to fibre-reinforced polypropylene mortars, which means that they could potentially be used as a replacement for some commercial fibres. Improvements in ductility were also reported for other natural fibres such as jute fibre [80] and banana fibre [67], which have lower tensile strengths compared to E. Globulus bark fibres (Table 3).

Since tensile strength is a relevant property in the ductile performance of the structure, it is possible to identify that the addition of E. Globulus may contribute to the improvement of this property. In fact, in the specific case of ductility, although not evaluated experimentally at this stage of the research, it could be visually observed that the samples with fibres were clearly less brittle than the control samples, i.e. without bark fibre reinforcement.

The improvement in concrete ductility can be useful in elements of low-budget housing, low-rise buildings and concrete pavements [70,81].

Additionally, the performance of plaster mortars could be improved by the application of natural fibres. In fact, Qamar et al. [82] reported that the addition of rice straw fibre, with a tensile strength 66% lower than the one of E. globulus bark fibres, increases the ductility of plaster mortars. Similarly, Rupasinghe and Sathiparan [83] indicate that coconut fibre reinforced mortars can control crack development, material ductility and post-peak load behaviour. Generally, unreinforced cementitious mortars as a surface plaster for masonry only improve the aesthetics, but not the structural behaviour. However, the inclusion of fibres may contribute to the prevention of brittle collapse [83].

4. Conclusions

Considering that the incorporation of natural fibres can produce a significant concrete strength reduction, the most important findings of this study were the results obtained for the concrete compressive and flexural strength. In effect, there is only a slight strength reduction when 0.5% of E. globulus bark fibre (with respect to the cement weight) is included. Furthermore, one of the results indicate that the strength difference cannot be considered significant as the reduction is less than the standard error.

Those are very important results because concrete strength is a fundamental characteristic related with the massive use of this material. Actually, compressive strength is a typical property tested in real structures when they are being built. For certain structures, as pavements, the flexural strength is tested instead. In addition to the favourable results of strength, the consistency results of the optimal bark fibre proportions are also appropriate, which is important as well, because in real-world structures, workability is also tested. Moreover, workability is directly related with the process of concrete mixing, placing and compacting. Moreover, adequate mix consistency also means that the composite concrete-bark fibre can be applied with traditional construction equipment. Even more, natural fibres as bark fibres of E. globulus are not abrasive to the processing equipment as some man-made fibres.

Hence, the chapter presents optimal results and proportions to promote the practical use of bark fibre of *E. globulus* in concrete applications. In fact, compared to proposed applications with other natural fibres, concrete reinforced with E. globulus bark fibres could be used to control micro-cracking of concrete. This is particularly relevant in structures that are exposed to demanding environments such as harbours and coastal buildings. Furthermore, increasing the ductility of concrete incorporated with E. globulus bark fibres can improve the in-service performance of housing, low-rise buildings, pavements and plaster mortars.

The results presented in this book chapter are an interesting antecedent to consider the reinforcement of concrete with Eucalyptus bark fibre, especially in countries with important areas of Eucalyptus, such as Australia, Spain, Portugal, Kenya, Brazil, or Uruguay. However, to evaluate the mechanical properties of those barks into the concrete, specific research is necessary.

In fact, the work presented in this article, attempts to contribute to the research related with understanding the properties of concrete reinforced with Eucalyptus bark fibres and its possibilities as an eco-friendly construction alternative to the concrete reinforced with man-made fibres. In effect, although there are numerous investigations about natural fibres, there is a lack of research related with the use of bark fibres of the E. globulus species in the concrete material. This is relevant because bark can be different between trees and even among Eucalyptus species.

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