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1 **Properties of composite laminates based on basalt fibers**
2 **with epoxidized vegetable oils**

3
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12
13 **Abstract**

14 This paper deals with the development of polymeric materials derived from
15 epoxidized vegetable oils which have been used in the manufacture of laminated
16 composite materials with basalt fabrics. Epoxidized linseed oil (ELO) and epoxidized
17 soybean oil (ESBO) were used as biobased matrices. The basalt fabrics were modified
18 with amino-silane and glycidyl-silane to increase fiber-matrix interactions. The curing
19 behaviour of both resins was evaluated by differential scanning calorimetry (DSC) and
20 oscillatory rheometry (OR). The evaluation of mechanical properties was made by
21 tensile, flexural and Charpy tests. The extent of the fiber-matrix interactions among
22 interface was evaluated by scanning electron microscopy (SEM). The obtained results
23 revealed that surface modification of basalt fibers with glycidyl-silane clearly improves
24 the mechanical properties of the composites. The use of the ELO resin as matrix for

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25 composite laminates improved substantially the mechanical performance compared to
26 composites made with ESBO.

27

28 **Keywords:** basalt fibres; epoxidized vegetable oils; silanes; mechanical
29 characterization.

30

31 **1.- Introduction.**

32 Composite materials with polymer matrices have traditionally been made with
33 petroleum-based thermosetting resins. Moreover, the use of polymeric materials from
34 non-renewable fossil resources is continuously increasing and there is a growing society
35 awareness for the conservation of the environment, making it necessary the
36 development of polymeric materials and composites made from renewable resources in
37 order to minimize the environmental impact. For this reason, and following promotion
38 from authorities and public bodies, the potential of renewable resources to displace or
39 replace petrochemical-based polymers has attracted the attention of many researchers
40 [1-6]. Vegetable oils are good candidates for polymer precursors since they are
41 composed of triglycerides with three fatty acids linked to a glycerol molecule. Most
42 common oils contain fatty acids whose length varies between 14 and 22 carbon atoms
43 with 0 to 3 carbon-carbon double bonds per fatty acid. The double bonds in triglycerides
44 offer the opportunity to modify their chemical structure in order to make them more
45 reactive. Therefore, it is possible to obtain different products such as epoxidized
46 vegetable oils (EVO), maleated vegetable oils (MVO) or hydroxylated vegetable oils
47 (HVO) as base materials for polymer synthesis and/or manufacturing [4]. The
48 epoxidation of vegetable oils introduces oxirane rings into carbon-carbon double bonds
49 in fatty acids by conventional epoxidation with peracids; this is one of the most

50 important oil functionalization processes known for many years [7, 8]. It is possible to
51 crosslink epoxidized vegetable oils with typical crosslinking agents or hardeners for
52 epoxies such as amines [9] and anhydrides [10]. Epoxidized vegetable oils, such as
53 epoxidized soybean oil (ESBO), epoxidized linseed oil (ELO), epoxidized canola oil
54 and epoxidized castor oil, among others, have been successfully used to prepare
55 thermosetting polymers and composite materials [4, 5, 10-13].

56 Glass, carbon and aramid fibers are widely used in composite manufacturing due
57 to their high performance, but they are expensive and their use causes a high
58 environmental impact. This is why in recent years, composites reinforced with natural
59 fibers have been increasingly developed [14-17]. However, the mechanical properties of
60 natural fibers are usually far from those provided by conventional glass, carbon or
61 aramids and this fact restricts their use in applications where high mechanical properties
62 are required. Glass fiber is, with difference, the most widely used reinforcement fiber
63 due to an excellent balance between properties and cost; in the last years other siliceous
64 fibers such as basalt and slate fibers have been tested as candidates for composite
65 manufacturing. Basalt fiber (BFs), obtained from the fusion of volcanic rocks, is a good
66 alternative to reinforce polymeric materials [18-20]. Its chemical composition is similar
67 to glass fibers, since basalt is mainly composed of Al_2O_3 , SiO_2 , CaO , MgO , K_2O , Na_2O ,
68 Fe_2O_3 y FeO [21, 22] and it has better mechanical properties than vegetable fibers and
69 slightly higher than conventional glass fibers. In recent years, BFs fabrics have been
70 investigated as reinforcement in polymer composites and they have been compared to
71 composites made with glass fibers [17, 21, 23].

72 One key factor to obtain optimum mechanical properties of composite materials
73 is ensuring good interaction between the matrix and the reinforcement which allows the
74 load transfer from the matrix to the reinforcement. If the interaction is weak, there is no

75 continuity in the material and the matrix will bear most of the load, thus resulting in
76 poor mechanical properties of the composite. In order to improve the interaction
77 between the fiber and matrix the surface of the reinforcement can be functionalized by
78 plasma treatment [24-26], or by the use of coupling agents such as amines [27, 28] or
79 silanes [18, 29]. The effectiveness of silanes on glass fiber has been widely studied; as
80 basalt fiber is a siliceous fiber, silanization is an interesting choice to improve fiber-
81 matrix interactions.

82 This paper intends to evaluate the efficiency of different silane (amine and
83 glycidyl) coupling agents in composite laminates of basalt fabrics with two different
84 epoxidized vegetable oils (epoxidized linseed oil-ELO and epoxidized soybean oil-
85 ESBO). The curing behaviour of the thermosetting resins is studied by differential
86 scanning calorimetry (DSC) and gel-time is determined by oscillatory rheometry (OR).
87 Laminate composites with basalt fabrics with different coupling silane agents and ELO
88 and ESBO are manufactured using resin transfer moulding (RTM) and the effect of the
89 silane treatment on mechanical properties of all composites are evaluated by tensile,
90 flexural and impact tests. Interface phenomena are followed by scanning electron
91 microscopy (SEM).

92

93 **2.- Experimental.**

94 **2.1.- Materials.**

95 Two types of commercial epoxidized vegetable oils were used as biobased
96 epoxy matrices: epoxidized linseed oil (ELO) with an epoxide equivalent weight (EEW)
97 of 178 g equiv⁻¹ and epoxidized soybean oil (ESBO) with an epoxide equivalent weight
98 of 238 g equiv⁻¹; both epoxidized oils were supplied by Traquisa SA (Madrid, Spain).
99 Liquid methyl nadic anhydride (MNA) was used as crosslinking agent; this product has

100 an anhydride equivalent weight (AEW) of 178.2 g equiv⁻¹ and it was supplied by
101 Sigma-Aldrich (Schnelldorf, Germany). The following resin formulation was used: the
102 EEW:AEW ratio was set at 1:0.9; propanediol (PDO) (1 wt.%) food grade was used as
103 initiator of the crosslinking reaction and it was supplied by Coralim Additives (Ribaroja
104 Turia, Spain) and finally, 1-methyl imidazole (1MI) (2 wt.%) was used as accelerator
105 and it was supplied by Sigma-Aldrich (Schnelldorf, Germany).

106 A basalt fabric with a surface density of 940 g m⁻² reference BAS 940.1270.T,
107 supplied by Basaltex (Basaltex, Wevelgem, Belgium) was used as reinforcement. Two
108 different silanes were used for surface modification and both were supplied by Sigma
109 Aldrich (Schnelldorf, Germany). The silane with amine functionality was [3 - (2-
110 aminoethylamine) propyl]-trimethoxysilane (Silane A) and the other one was glycidyl
111 trimethoxysilane [2 - (7-oxabicyclo [4.1.0] hept-3-yl) ethyl] silane (Silane B). Scheme 1
112 shows the chemical structures of the different components used for thermosetting
113 formulation as well as silanization. With regard to epoxidized linseed oil (ELO) and
114 epoxidized soybean oil (ESBO), Scheme 1 shows the theoretical structures obtained
115 after full conversion of carbon-carbon double bonds into oxirane rings. Usually, full
116 conversion is not achieved and on the other hand, some other parallel reactions (i.e.
117 homopolymerization) can occur thus leading to slightly different chemical structures.

118

119 **Scheme 1**

120

121 ***2.2.- Silane treatment of basalt fibers.***

122 Before applying the treatment with silanes, basalt fabrics were heated in an oven
123 at 300 °C for 2 hours in order to remove previous organic sizings. The silanes (1 wt.%)
124 were diluted in a water acetone solution (volume ratio 50:50) and basalt fabrics were

125 immersed in the solutions for 1 hour and finally they were washed with distilled water
126 and dried at room temperature for 24 hours. Three types of basalt fabrics were obtained:
127 basalt fabric with thermal treatment is referred as Basalt TT, basalt fabric treated with
128 amino-silane, which is referred to as Basalt A, and finally basalt fabric treated with
129 glycidyl-silane which is referred as Basalt B.

130

131 ***2.3.- Composite manufacturing.***

132 The manufacturing of composite laminates was carried out using a resin transfer
133 moulding (RTM) process in a Hypaject MKII machine (Plastech Thermoset Tectonics,
134 Gunnislake, UK). A vacuum pump was connected in the vent hole of the mould in order
135 to improve the air evacuation and to avoid bubble trapping in the laminate. The
136 processing conditions for composite laminates are summarized in Table 1. Four basalt
137 fabric layers were stacked in the same directions (0/90°) for composite manufacturing.
138 The total fiber content was close to 57 wt.% (57.3 wt.% for composites with epoxidized
139 linseed oil-ELO and 56.2 wt.% for composites with epoxidized soybean oil-ESBO).

140

141 **Table 1**

142

143 ***2.4.- Characterization of the curing process.***

144 The study of the curing process of epoxidized vegetable oils (ELO and ESBO)
145 was performed using dynamic differential scanning calorimetry in a Mettler Toledo
146 DSC 821e (Mettler Toledo SAE, Barcelona, Spain) under nitrogen atmosphere. The
147 first step of thermal heat program consisted in heating from 30 to 300 °C at a heating
148 rate of 5 °C min⁻¹. Then cooling was performed from 30 °C to -10 °C min⁻¹ and finally a
149 second heating was performed from 30 °C up to 350 °C at 5 °C min⁻¹.

150 Additionally, the isothermal curing of the epoxidized vegetable oils was also
151 followed by plate-plate oscillatory rheometry in an AR-G2 (TA Instruments, New
152 Castle, USA). The analysis was conducted using a configuration of two parallel plates
153 ($D = 25$ mm). Four different isothermal temperatures (90, 100, 110 and 120 °C) were
154 used until it was observed that the material was fully cured ($\delta = 0^\circ$). The controlled
155 variables were 0.1% strain (γ) at a constant frequency of 1 Hz.

156

157 ***2.5.- Mechanical testing.***

158 Tensile tests were conducted on a universal testing machine Instron Model 3382
159 with a load cell of 100 kN and a crosshead rate of 2 mm min⁻¹; all tests were performed
160 according to ASTM D3039-08. Flexural tests were performed on a universal testing
161 machine model LLOYD 30 K with a load cell of 500 N and a crosshead rate of 1.7 mm
162 min⁻¹ according to ASTM D790-10. Impact tests were performed according to ISO 179
163 standard, using a 6 J Charpy impact pendulum (Metrotec SA, San Sebastian, Spain).
164 Five different samples were tested for each characterization test and average values
165 were calculated.

166

167 ***2.6.- Microscopic analysis of the fractured surfaces.***

168 The analysis of the fractured surfaces was performed with cryofractured (in
169 liquid nitrogen) samples; then samples were coated by gold sputtering and finally they
170 were observed by scanning electron microscopy (SEM) in a Phenom SEM (FEI
171 Company, Eindhoven, The Netherlands) at an acceleration voltage of 5 kV.

172

173 **3.- Results and discussion.**

174 ***3.1.- Characterization of the curing process of epoxidized vegetable oils.***

175 The curing of the two biobased epoxy resins (ELO and ESBO) was followed up
176 with dynamic differential scanning calorimetry (DSC); curing temperature and time are
177 key parameters since a proper curing of the resin is one of the main issues to be
178 considered in order to obtain composites with good properties. The main calorimetric
179 parameters obtained from the corresponding calorimetric (DSC) curves of both resins
180 can be observed in Table 2. Curing of ELO resin proceeds with a maximum reaction
181 rate located at 175.7 °C. No residual heat is released in the second heating step so that,
182 the material is fully cured. With regards to curing of epoxidized soybean oil (ESBO) the
183 maximum curing rate (temperature peak) is moved to higher temperature (183.2 °C) and
184 no residual released heat is detected in the second heating step thus indicating full
185 curing during the first heating. The glass transition temperature is not easy observable in
186 the second heating program. In addition, the exothermicity of the two crosslinking
187 processes is different with values of 118.9 J g⁻¹ for epoxidized linseed oil (ELO), and
188 91.4 J g⁻¹ for epoxidized soybean oil (ESBO). These values are in total agreement with
189 the chemical structure of both epoxidized vegetable oils. Epoxidized linseed oil is
190 characterized by an EEW of 178 g equiv⁻¹ while epoxidized soybean oil has an EEW of
191 238 g equiv⁻¹. These values indicate that for a similar molecular weight of the vegetable
192 oil, ELO has more epoxide groups than ESBO. For this reason, ELO reactivity is higher
193 and, consequently, the exothermicity is higher.

194

195

Table 2

196

197 The curing gel time of both epoxidized vegetable oils at different temperatures
198 in the 90-120 °C range was determined using plate-plate oscillatory rheometry by
199 following the evolution of the phase angle (δ). Initially phase angle values are close to

200 90° which is representative for liquids thus indicating that when a sinusoidal (dynamic)
201 stress is applied to a liquid, the corresponding response (elongation-deformation) also
202 follows a sinusoidal type but delayed by 90° with regard to the applied stress. The
203 crosslinked resin behaves as an elastic solid material and is characterized by a phase
204 angle of near 0° (this means no phase angle between the applied dynamic stress and the
205 corresponding dynamic deformation). The phase angle decreases as the curing process
206 starts and the phase angle is close to 0° when the resin is fully cured; the gel time can be
207 defined as the midpoint between a fully liquid state and the fully cured crosslinked resin
208 with (elastic solid); as the phase angle changes from 90° (liquid) to 0° (elastic solids),
209 the gel time can be defined as the time to reach a phase angle of 45° which, in turn,
210 implicate that the storage modulus (G') and the loss modulus (G'') are identical
211 (crossover point). Fig. 1 shows the phase angle as a function of time for the isothermal
212 curing of both epoxidized vegetable oils (ELO and ESBO). In both cases, it can be
213 clearly seen that the gel time ($\delta = 45^\circ$) occurs at lower times as temperature increases.
214 The minimum value is reached at a temperature of 120°C with gel time values of 1497 s
215 for ELO and 2750 s for ESBO. These results indicate that curing of ELO requires less
216 time than ESBO due to the higher EEW of ELO if compared to ESBO. Table 3
217 summarizes the gel time for both epoxidized vegetable oils at different temperatures.

218

219

Figure 1

220

Table 3

221

222

223

224

By considering the data obtained by differential scanning calorimetry (DSC) and oscillatory rheometry (OR) it was decided that 100 °C is a proper temperature for crosslinking both epoxidized vegetable oils since balanced curing cycles can be

225 designed (moderate temperatures and moderate curing times). At 120 °C the curing in
226 both resins starts very fast and it can produce problems in the filling process by RTM
227 during composite laminate manufacturing. Regarding the epoxidized soybean oil
228 (ESBO) thermosetting resin, it is important to remark that it needs longer curing time as
229 it is characterized by a lower reactivity than the epoxidized linseed oil (ELO).

230

231 ***3.2.- Mechanical characterization of basalt-EVO composite laminates.***

232 Fig. 2 shows the tensile behaviour of basalt-EVO composites; the tensile moduli
233 do not vary significantly with the use of the two different silanes in comparison to
234 untreated basalt fabrics. However the tensile strength increases significantly in
235 composites with basalt fabrics subjected to silanization, independently of the epoxidized
236 vegetable oil used as composite matrix. In both resins the highest value for tensile
237 strength is obtained with the basalt fabrics previously treated with the glycidyl-silane
238 (Silane B). In the case of composites manufactured with ELO matrix and basalt fabrics
239 subjected to prior silanization with glycidyl-silane, a clear increase in tensile strength is
240 observed from 330.8 MPa (not silanized basalt fabric, only with thermal treatment to
241 remove previous sizing, ELO-Basalt TT) up to 366.2 MPa which represents a
242 percentage increase of 10.7%. In the case of epoxidized soybean oil (ESBO), a similar
243 increase is detected from 288.8 MPa (ESBO-Basalt TT) up to 328.6 MPa (percentage
244 increase of about 13.8%) for composite laminates with previous glycidyl-silane
245 treatment.

246

247

Figure 2

248

249 A comparison of the flexural properties of basalt-EVO composite laminates (Fig.
250 3) shows in a clear way a remarkable increase in both modulus and strength values for
251 silanized basalt fabrics. These results indicate that once again, the glycidyl-silane (silane
252 B) offers better mechanical performance than the amino-functionalized silane in both
253 epoxidized vegetable oils although both silanes gives higher properties than untreated
254 basalt fabrics. With regard to epoxidized linseed oil (ELO) as matrix for basalt
255 composite laminates, the flexural strength of laminates with non-silanized basalt fabrics
256 (ELO-Basalt TT) is of about 146.2 MPa and this value is substantially increased up to
257 twice (300.2 MPa) in laminates with glycidyl-silane pre-treatment. This situation is
258 more pronounced in composite laminates with epoxidized soybean oil (ESBO) in
259 which, the flexural strength changes from 93.1 MPa (ESBO-Basalt TT) up to 238.9
260 MPa (ESBO-Basalt B) with previously glycidyl silanized basalt fabrics. With regards to
261 flexural modulus, we can see a clear increase with the silane treatment with identical
262 tendency of that observed in tensile strength.

263

264

Figure 3

265

266 Obviously, as epoxidized linseed oil (ELO) is characterized by higher EEW than
267 epoxidized soybean oil (ESBO), crosslinked ELO gives stiffer materials than in the case
268 of ESBO as ELO possesses more epoxide groups per oil molecule. If we compare the
269 obtained results with other studies with composite laminates with similar weight
270 percentage fiber content (mainly glass) and petroleum-based epoxy matrices, it is
271 important to remark that basalt-ELO composites offer similar performance thus
272 providing a high environmental efficiency solution for medium-high performance
273 composite laminates [21, 30, 31].

274 Table 4 shows a summary of the results obtained in Charpy impact tests.
275 Composites made with ESBO matrix absorb more energy than composites made with
276 ELO matrix. This behaviour is due to the fact that ESBO has a lower crosslinking
277 density than ELO leading to a more flexible network. Therefore, the obtained
278 composites are less resistant but they are more ductile and therefore they can absorb
279 more energy during the deformation and fracture processes. It can also be observed that
280 the silane treatment on basalt fabrics improves the energy absorption.

281

282 **Table 4**

283

284 ***3.3.- Analysis of the fracture surface.***

285 In addition to mechanical characterization, a morphological analysis of
286 cryogenically fractured samples was performed in order to determine the degree of
287 interaction between the basalt fiber and the epoxidized vegetable oil (EVO) matrix. Fig.
288 4 shows the SEM images corresponding to epoxidized linseed oil composites with
289 basalt fabrics subjected to different silanes. Fig. 4a & 4b show the SEM images of
290 basalt-ELO composite laminates without silane treatment (only thermal treatment to
291 remove previous sizings). We can clearly see that the interaction between the fiber and
292 the matrix is very poor, since there are gaps around the fiber; these gaps act as stress
293 concentrators as they do not allow good load transfer from the matrix to the fiber; we
294 can also observe that the longitudinal surfaces of the fibers are very clean, with no
295 residual matrix which is representative for poor matrix-fiber adhesion. These facts
296 indicate a lack of interaction between the fiber and the matrix limiting the strength of
297 the laminate. However, Fig. 4c & 4d show the fracture surfaces of composites with ELO
298 and amine-silanized basalt fabrics (ELO-Basalt A). We can clearly observe differences

299 with the above mentioned untreated basalt fabrics. The existing gaps have been
300 substantially reduced and this has a positive effect on fiber-matrix continuity so that,
301 load transfer occurs and the matrix is able to transfer almost all the stresses to the stiffer
302 component. In the case of glycidyl-silanized basalt fabrics (Fig. 4e & 4f) we observe a
303 similar morphology and it is evident that the silane treatment has improved fiber-matrix
304 interactions and, as described previously, this has a positive effect on the overall
305 mechanical performance.

306 In relation to composites with basalt fabrics and epoxidized soybean oil (ESBO)
307 matrix, Fig. 5 shows SEM images for different treatments. Once again we observe the
308 presence of gaps in the fiber surroundings in composites without silane treatment (Fig.
309 5a & 5b) thus indicating poor interactions which, in turn, are responsible for the low
310 mechanical performance. Fig. 5c & 5d (ESBO-Basalt A) and Fig. 5e & 5f (ESBO-
311 Basalt B) correspond to amine-silane and glycidyl-silane treatment on basalt fabrics
312 respectively and we can clearly see an increase in adhesion between the fiber and the
313 matrix, which is translated into an improvement of the mechanical properties as
314 described before.

315

316 **Figure 4**

317 **Figure 5**

318

319 **4.- Conclusions.**

320 In this work the influence of the silane treatment on mechanical properties of
321 composite laminates manufactured with two different biobased epoxy resins
322 (epoxidized linseed oil-ELO and epoxidized soybean oil-ESBO) has been evaluated.
323 Composites with these biobased epoxies can be manufactured by conventional RTM

324 process and, in general terms, composites with previous silane treatment on basalt
325 fabrics offer better mechanical performance than untreated basalt fabrics. The best
326 results are obtained using basalt fabrics modified with a glycidyl silane (trimethoxy [2 -
327 (7-oxabicyclo [4.1.0] hept-3-yl) ethyl] silane) with both ELO and ESBO matrices.
328 Generally, composites made with epoxidized linseed oil (ELO) have better strength
329 properties than ESBO composites; that is due to the fact that ELO enables a higher
330 crosslinking density due to a higher equivalent epoxide weight (EEW) but, in contrast,
331 composites manufactured with ESBO matrix have the ability to absorb more impact
332 energy taking advantage of the lower crosslinking density compared to ELO.
333 Silanization of basalt fibers highly improves fiber-matrix interactions as detected by
334 SEM analysis. There is a lack of gaps between the fiber and the surrounding matrix, due
335 to improved wetting properties. In general terms, both amino- and glycidyl- silanes
336 contribute to improve mechanical performance of the manufactured composites with
337 basalt fabrics, although slightly better results are obtained with glycidyl silanes.

338

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342

343

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434 **Figure legends**

435 **Scheme 1.-** Chemical structure of chemicals used: a) epoxidized linseed oil (ELO, b)
436 epoxidized soybean oil (ESBO), c) methyl nadic anhydride (MNA), d) propanediol
437 (PDO), e) 1-methyl imidazole, f) [3 - (2-aminoethylamine) propyl]-trimethoxysilane
438 and g) [2 - (7-oxabicyclo [4.1.0] hept-3-yl) ethyl] silane.

439 **Figure 1.-** Phase angle (δ) as a function of the curing time at different isothermal curing
440 temperatures obtained by oscillatory rheometry (OR) for a) epoxidized linseed oil
441 (ELO) and b) epoxidized soybean oil (ESBO), cured with methyl nadic anhydride
442 (MNA).

443 **Figure 2.-** Comparison of the tensile properties of basalt-EVO composite laminates
444 with different surface treatments.

445 **Figure 3.-** Comparison of the flexural properties of basalt-EVO composite laminates
446 with different surface treatments.

447 **Figure 4.-** SEM images at 3000x (a, c and e) and 5000x (b, d and f) of ELO-Basalt TT
448 samples (a & b) ELO-Basalt A (c & d) and ELO-Basalt B (e & f).

449 **Figure 5.-** SEM images at 3000x (a, c and e) and 5000x (b, d and f) of ESBO-Basalt
450 TT samples (a & b) ESBO-Basalt A (c & d) and ESBO-Basalt B (e & f).

451

452

Table 1.- Processing conditions of epoxidized vegetable oil (EVO)-basalt fabric (BF) composite laminates by resin transfer moulding (RTM).

Parameter		ELO matrix	ESBO matrix
Resin Injection temperature (°C)		60	60
Resin injection pressure (kPa)		100	100
In mould cavity pressure (kPa)		95	95
Curing cycle	Temperature (°C)	100	100
	Time (h)	3.0	3.5
Demoulding temperature (°C)		30	30

Table 2.- Main characteristics of the curing process of epoxidized linseed oil (ELO) with methyl nadic anhydride (MNA) and epoxidized soybean oil (ESBO) with MNA obtained by dynamical differential scanning calorimetry (DSC).

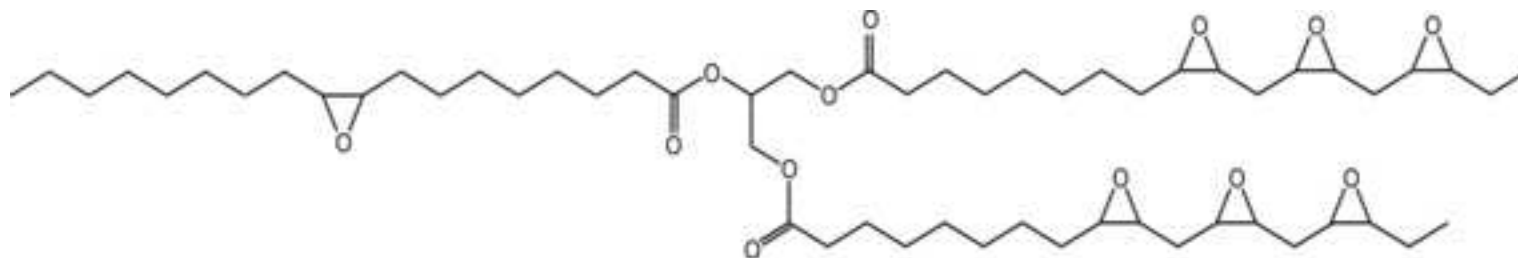
Parameter [1st heating]	ELO-MNA	ESBO-MNA
Onset (°C)	143.4	154.2
Endset (°C)	231.2	233.4
Peak (°C)	175.7	183.2
Enthalpy (J g ⁻¹)	118.9	91.4

Table 3.- Characterization of the crossover point in which $G'=G''$ values of the isothermal curing by plate-plate rheometry of ELO & ESBO resins, for gel time determination.

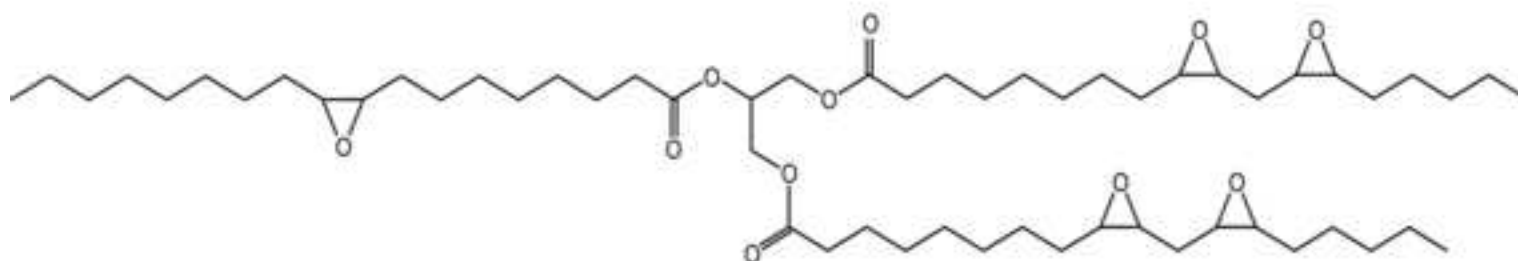
Temperature (°C)	ELO matrix		ESBO matrix	
	$G'=G''$ (Pa)	Time (s)	$G'=G''$ (Pa)	Time (s)
90	623	9453	565	17961
100	195	4560	231	9008
110	139	2787	414	4309
120	171	800	96	2748

Table 4.- Values of Charpy impact energy for epoxidized vegetable oil (EVO)-basalt fabric (BF) composite laminates.

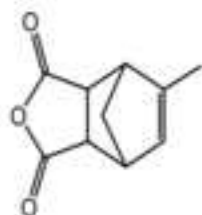
Samples	Silane type	Charpy impact energy (kJ m⁻²)	Standard deviation
ELO-BasaltTT	--	116.5	1.9
ELO-BasaltA	amino	149.0	4.6
ELO-BasaltB	glycidyl	123.5	22.1
ESBO-BasaltTT	--	118.5	10.2
ESBO-BasaltA	amino	142.5	11.6
ESBO-BasaltB	glycidyl	151.5	7.6



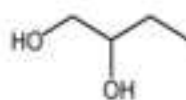
a) epoxidized linseed oil (ELO)



b) epoxidized soybean oil (ESBO)



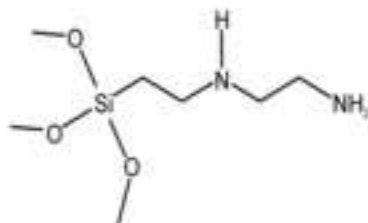
c) methyl nadic anhydride (MNA)



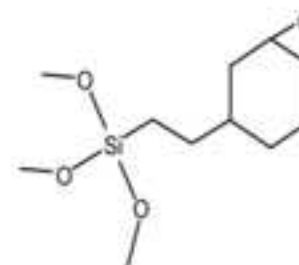
d) 1,2 propanediol (PDO)



e) 1-methyl imidazole (1-MI)



f) [3 - (2-aminoethylamine) propyl]-trimethoxysilane



g) [2 - (7-oxabicyclo [4.1.0] hept-3-yl) ethyl] silane

