Study Regarding the Mechanical Behavoiur of Dammar Based Composite Materials, Reinforced with Natural Fiber Fabrics

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In this paper, were determined the mechanical properties for Dammar based composite materials. For the begining, were determined the mechanical properties (elasticity modulus, breaking strength, breaking elongation, transversal Poisson ratio) for samples made from a resin whose Dammar is its main part. Based on this resin, were made composite materials, using as reinforcement fabrics from cotton, silk, flax and hemp. For each composite type were experimentally determined the same mechanical properties as in the case of resin based samples.

Keywords: textile composites, mechanical properties, stress/strain curves, elastic properties, fractography

Lately, there is a high interest in using natural fibers for composite materials manufacturing [1]. From this fibers category, I can enumerate the flax, hemp, jute, sisal, kenaf, coconut, kapok, bananas, henequen and others [2]. The natural fibers represent adequate reinforcing materials for composites because of the combination between good mechanical properties and the advantages in the enviroment protection (regeneration and biodegradability [3,4]).

The usage of natural fibers as reinforcement presents many advantages, such as: relatively low cost, abundance in nature, low weight, less damages to manufacturing equipments, good surface finishing for molded products (compared to the composites glass fiber based), good relative mechanical properties.

From the disadvantages of the natural fibers I can mention: their manufacturing is limited to the lower temperatures processing (limited thermal stability), their tendency to form bundels, hydrophilic nature [5-7]. The experimental data of their mechanical properties in different manufacturing conditions have shown in many cases unsubstantial values [1,3,4], and the irregular characteristics from the fibers can represent a possible explanation. In many situations, problems regarding the interfacial properties appear at these types of composites, fact that leads to undesired properties for them [1,3,4].

The natural fibers hydrophilic character creates a low compatibility with polymeric matrices and produces a decreased dimensional stability, because the fibers are expanding after the water absortion [5,8-12]. In order to decrease this character, the fibers surface is necessary to be modified by using some chemical treatments which increase the adhesion between the fibers and the matrix [4].

Apart from the fibers hydrophilic nature, the composites properties reinforced with natural fibers can also be influenced by the ratio between the fibers and the filling matrix. Generally, a high fibers content is needed to obtain a high composite performance. Therefore, the effect of the fibers content over the composite materials reinforced with natural fibers properties is extremely important [13]. There has been found that the tensile strength values of composites reinforced with natural fibers has increased with the fibers percentage until a maximum or an optimal value before decreasing again. Nevertheless, generally it is true that the Young modulus values have gradually increased with the fibers percentage increase [14].

Some researchers have found the exact opposite tendency to the strength composite increase with the fibers percentage increase. This thing can be assimilated to many factors, such as: the incompatibility between the fibers and the matrix, inadequate manufacturing technologies, fibers degradation and others. The different chemical surface changes, such as the chemical treatments for increasing the tensile properties of natural fiber based composites, have been made by a large number of researchers [15-19]. The results of these researches and the natural fibers mechanical properties are presented and centralized in some papers [20-24].

The weak compatibility of the natural fibers with more polymeric matrices can lead to non-uniform fibers dispersion inside the matrix. The thermoplastic materials lately prevail, as matrix for bio-fibers. The most frequently used thermoplastic materials for this purpose are polypropylene, polyethylene and polyvynilchloride.

From the thermorigid matrices, the modes used are the ambresits, epoxy and polyester resins [4]. On one hand, the traditional thermorigid matrices make the global product not to be easily recycled, and on the other hand, the traditional thermoplastic matrices have limitations such as: increased melting viscosity, a dangerous problem in the case of injection molding manufacturing. In order to remove these disadvantages, it was tried the usage of thermorigid-biological matrices (plant oil based matrices, soy resin or other vegetable oils) manufactured to be biodegradable [5,25,26]. The thermoplastic bio-materials are prefered to be chosen, because they do not need the polymerisation process and combine both advantages of recycling and removing in perspective.

The natural resins are insoluble in water, but slightly soluble in oil, alcohol and partially in gas. With certain organic solvents they form liquors used as covering liquids. The turpenting, rosin, mastic are products resulted from pine resins distillation. A study regarding their chemical composition is made in [27]. The vegetable resins are Sandarac, Copal and Dammar. From the fossils resins, the amber can be remembered and the Shellac, from the animal ones.

A major disadvantage for this resins types is their high cost which makes them unapproachable even for large

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scale production. Other disadvantages for resins based on bio concept include brittleness, low temperature for hot deformation, high permeability at gases, an inadequate melting viscosity for a later manufacturing. All these disadvantages restrain their usage in a large area of applications [28].

In this paper was studied the mechanical behaviour for some composite materials that have as matrix a combination between Dammar and epoxy resin. As reinforcing materials were used flax, hemp, cotton and silk fibers. I have determined both the mechanical characteristics for the used resin and for the composite materials obtained by its reinforcement with the told fabrics.

Experimental part

The composite materials allow the obtaining of a high mechanical properties diversity, fact that makes very difficult the mechanical characteristics calculus versus the parts percentage. All the ways of properties and behaviour investigations for composite materials present the difficulty that a high number of elastic constants is necessary to be known, and the obtained models are complex. The most important factors that depend on the composites mechanical and elastic properties are: the elastic and mechanical properties of the constituents; the constituents volumic percentage; the constituents geometrical arrangement; the adhesion between the composite compound materials; the fibers length; the manufacturing process.

In order to evaluate the composite material breaking strength, the fibers are considered to have an elastic behaviour until the breaking, and the matrix has a non-linear behaviour in the case of fibers breaking maximum deformation exceeding. In the case of a unidirectional composite tensile loaded in the fibers length, the breakage is considered to be produced when the fibers fail. The practical results show that the maximum medium stress value has lower values in comparison to the ones theoretically obtained in the previous hypothesis. This can be explained by the fact that not all the fibers have the same breaking strength, some of them fail and the loading is taken over by the unbroken fibers.

In case the fibers used for reinforcement present after an elastic behaviour area a plastic behaviour one, then the composite material may have a non-linear behaviour and the breaking strength theoretical determination may be very difficult. Experimental determinations in this case are necessary to be made. Even more, the experimental determinations are imposed in the case of natural based resins composites, reinforced with natural fibers, because the properties depend on many factors.

These aspects show that, in the case of new composite materials, it is necessary to obtain the mechanical properties experimentally. I have made Dammar based natural resin samples. This, diluted with turpentine, strengthens in time if it is applied in thin layers. If it is kept in containers, it remains in liquid shape. The composite materials based only on this resin have a very long time to strengthen. In order to remove this deficiency, I have made a combination between natural and epoxy resin. In this combination, 60 % is Dammar, and 40 % is epoxy resin.

From this resin, I have made more samples sets with densities between 1.04 - 1.05 g/cm^3.

The samples were tensile loaded, made according to SR EN ISO 6892-1:2010 standard. I have used the universal static and dynamic testing machine, with maximum load of 300 kN and which can be used for static loadings at

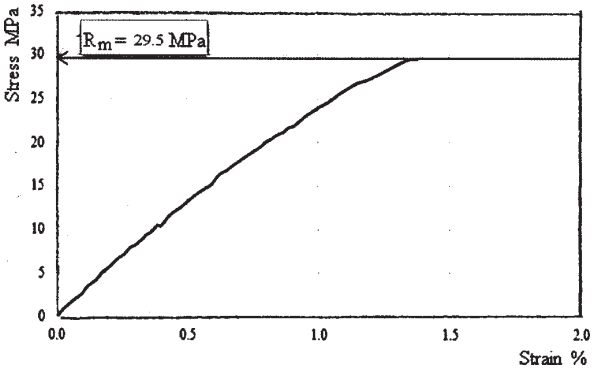

Fig. 1 The characteristic resin curve for a representative sample

tensile, compression, bending, shear, fatigue, fracture mechanics loadings or other types of mechanical loadings according to the international domain standards.

In figure 1, the characteristic curve for a representative sample from this resin is presented. I have wanted to determine especially the breaking strength, breaking elongation, transversal Poisson ratio and the elasticity modulus.

The main mechanical characteristics obtained for the Dammar samples are:

-the breaking strength between 25-29.5 MPa, with the representative value of R_m = 29 MPa;

-the breaking elongation between 1.1-1.4%, with the representative value of A = 14%;

-the transversal Poisson ratio between 0.5-0.6, with the representative value of μ = 0.57;

-the elasticity modulus between 2210-2560 MPa, with the representative value of E =2463.

For each mechanical characteristic result, the representative value was determined as the mean value obtained for three samples that had the highest breaking strength values.

I have made samples from this combined resin reinforced with:

-mixture fabric from 40% cotton and 60% flax (abbreviated as DI), with the speciffic mass 240 g/cm^2. I have used 12 layers, the obtained composite has the masic percentage resin of 0.52, the resin percentage volume 0.57 and density 1.21.g/cm^3;

-mixture fabric from 60 % silk and 40 % cotton (abbreviated as DM), with the speciffic mass 162 g/cm^2. I have used 20 layers, the obtained composite has the masic percentage resin of 0.51, the resin percentage volume 0.61 and density 1.16 1g/cm^3;

-cotton fabric (abbreviated as DB), with the speciffic mass 126 g/cm^2. I have used 24 layers, the obtained composite has the masic percentage resin of 0.5, the resin percentage volume 0.58 and density 1.18 g/cm^3 ;

-hemp fabric (abbreviated as DC), with the speciffic mass 352 g/cm^2. I have used 6 layers, the obtained composite has the masic percentage resin of 0.62, the resin percentage volume 0.66 and density 1.10 g/cm^3.

I have preferred to give the resin masic and volume percentages because I could determine the reinforcement and resin mass for each sample set. By knowing the resin density, I have determined the resin volume from the samples.

The composite materials properties reinforced with natural fibers can be very different because of these fibers variations. Even in the engineering literature, there are differences of estimation.

The used reinforcements for manufacturing the composite materials are usually used in the textile industry and did not require special treatments.

All the samples types were tensile tested.

Results and discussions

In the figures 2-3, the representative characteristic curves for the DM and DB samples are presented.

The analysis of these curves highlights the existence of three stages in the loading and deformation process. In the first step, there is a proportionality between the stress and strain in which the Hooke law is checked. In the second stage, there is a non-linear character, in this area there can be found the point where the yield stress appears for which residual strains of 0.2% appear after stopping the loading. It is observed that the strain in this stage is very close to the one that appears at the resin breaking. In the third stage, reappears the dependance between the stresses and the strains. This form of the characteristic

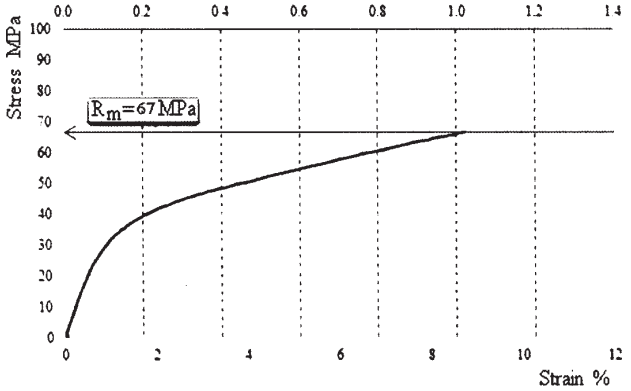

Fig. 2 Representative characteristic curve for DB samples

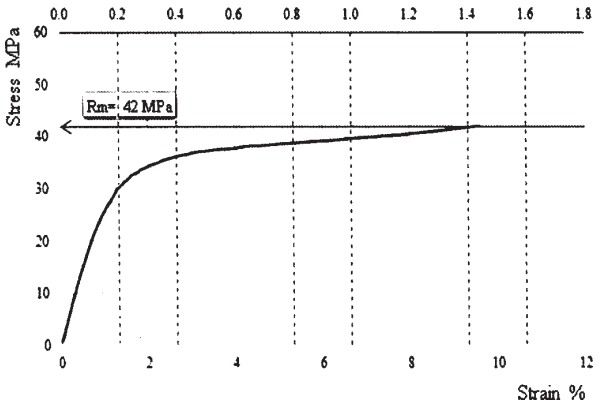

Fig. 3 Representative characteristic curve for DM samples

curve can be explained by the next loading phenomenon mechanism.

In the first stage, the loading is taken over by both the longitudinal places fibers and the matrix that assures the composite material adhesion.

The Hook law can be accepted as valid:

$$\sigma = E \cdot \varepsilon , \qquad (1)$$

where E is the longitudinal elasticity modulus on the loading direction.

This can be determined with the relation:

$$E = kE_f V_f + E_m V_m \qquad (2)$$

in which:

- E_f is the longitudinal elasticity modulus (Young) for the fibers;
- E_m is the longitudinal elasticity modulus (Young) for the matrix;
- V_f is the fibers volumic percentage;
- V_m is the matrix volumic percentage;

$$k = \frac{n_1}{n_1 + n_2} . \qquad (3)$$

where n_1 is the number of fibers from the fabric placed on the loading direction, and n_2 is the fibers number from the fabric placed on the loading perpendicular direction.

So, I consider that only the fibers aranged along the tensile test direction are loaded. For the composite material building, the fibers layers were arranged to obtain $n_1 = n_2$, therefore k = 0.5.

In the second stage, the dependance stress – strain becomes non-linear. This thing appears due to two phenomena:

- in the resin the breaking strength appears and it fails in certain points;
- the adhesion between fibers and matrix is lost and fibers pluckings from the matrix appear.

As consequences of these phenomena, there is produced a loading transfer to the fibers. If, at the begining of this stage, the loading was distributed in all of the composite volume, being taken over by both the matrix and reinforcement, at the end of this stage, the loading can be considered to be taken especially by the fibers.

In the third stage, the dependance between stress – strain gains again a linear character. This thing suggest that the fabric fibers which are longitudinally placed take over the whole loading, and the composite breakage is made when the breaking strength is reached in the fibers. In this hypothesis, the composite breaking strength can be approximated with the relation:

$$\sigma_r = k\sigma_f V_f \qquad (4)$$

where σ_f is the fibers breaking strength.

A similar shape for the characteristic curve can bee seen for DI type samples, which is presented in figure 4, but the passings from a domain to another are not so obvious.

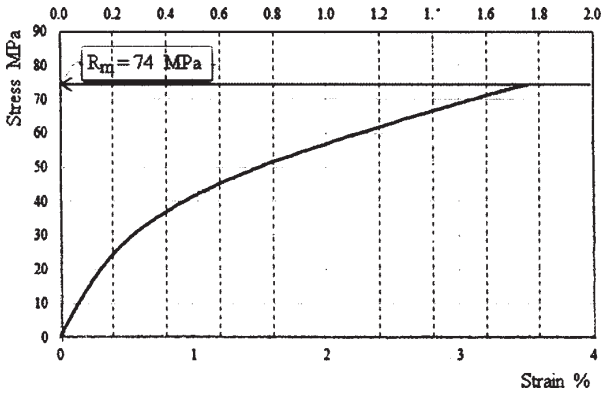

Fig. 4 Representative characteristic curve for DI samples

The characteristiv curve shape for DC type sample, presented in figure 5, is very different, being very close to a linear shape.

In the table 1, the determined values of mechanical characteristics are presented for the studied composite materials.

The breaking sections and characteristic curves analysis shows that the breakage is suddenly made, although the ways for which the breakage appears can be different from a composite material to another.

Therefore, a breakage type appears when the matrix is dettached from the fibers (which were plucked from the resin) and a breakage type that, with the fibers failure the matrix is broken too, keeping its contact with the fibers in the place where the breakage took place (made by a perpendicular direction on the loading direction).

Sample type	Tensile strength R_m (MPa)	Yield strength $R_{p0.2}$ (MPa)	Breaking Elongation (%)	Elasticity Modulus (MPa)	Poisson ratio
DB	66	34.5	8.9	4134	0.24
DM	43	33	10.1	3087	0.36
DI	74	44	3.4	5982	0.37
DC	75	-	2.3	6548	0.51

Table 1

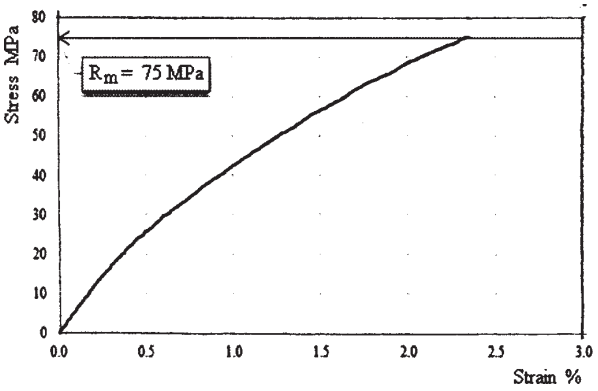

Fig. 5 Representative characteristic curve for DC samples

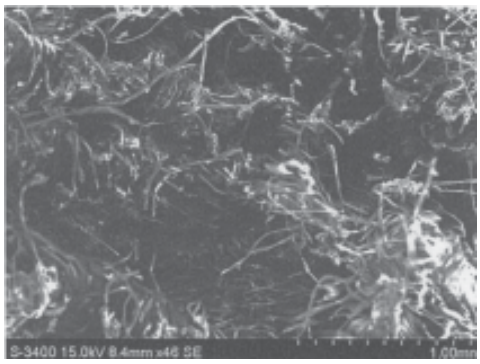

Fig. 6 The representative image for the breaking strength area for DI samples

The first breaking type has appeared to the DM and DB samples, which were reinforced with fibers that have a high breaking elongation (7-8 % for cotton and 19-20 % for silk).

The second breaking type has appeared to the DC and DI samples, which were reinforced with fibers that have a low breaking elongation (1.6-4 % for hemp and 2.7-3.2 % for flax).

Significant differences are observed for the characteristic curves. In the case of DB and DM type samples, that have a high breaking elongation for the reinforcement, the composite materials have also a high breaking elongation. For these composite types, three different areas were highlighted where the mechanical behaviour presents changes depending on the way the external loading is distributed between the matrix and reinforcement. In the case of DC type samples, where the breaking elongation of reinforcement is low, the non-linearity of the characteristic cuve is smaller, so it appears from the beginning of the loading. This thing can be explained by the fact that the matrix and reinforcement take over together the external loading during the whole tensile test. The DI type samples have an intermediate behaviour.

In figure 6, it is presented the breaking strength area image for this samples type. For the other samples types (DB, DM, DC) the breaking area image is similar.

If the usual values of the elasticity modulus for reinforcing fabrics are taken into account $E_{cot\,ton}$=12 GPa, E_{flax}=27 GPa, E_{silk}=5.8 GPa,E_{hemp}=30 GPa and the parts volumic percentages are taken into account, there are obtained, with relation (2), for the studied composite materials, values of the elasticity modulus close to the ones experimentally determined. The next values are obtained: E_{DB}=3984 MPa, E_{DM}=3104 MPa, E_{DI}=5838MPa, E_{DC}=6726 MPa.

In the case of breaking strength, the relation (4) leads to values close to the experimental ones. The only exception is represented by the breaking strength for DC samples types for which, in order to have the relation (4) valid, it is necessary to consider for hemp σ_f=440 MPa, which is a lower value compared to the ones from the composites engineering literature.

An explanation consists in the fact that the hemp fibers were braided in wires with much higher dimensions in comparison with other fabrics. It was lost in this way the synergy effect highlighted by the reinforcing material properties.

Another explanation consists in the fact that, for the fiber reinforced composites, the interface that separates the matrix from the reinforcement is, in most cases, perceived as having a high influence over the material stiffness and over the characteristics regarding its tolerance to damage (meaning the random phases separation), and in this case it presents deficiencies.

Conclusions

The rythme of random detachment cluster, in the case of less performance interfaces, often depends on the interface mechanical loading response, that can speed up the total phase separation at the interface level, under the form of a total detachment ductile or brittle type.

In the case of many fiber reinforced composites, the weaker interfaces are somehow wanted, if they bring an increase to the materials ductility, but also, this thing can appear because of the stiffness decrease.

References

1.OKSMAN, K., Mechanical properties of natural fibre mat reinforced thermoplastic, Appl. Compos. Mater., 7, 2000, p. 403–414.

2.LI, X., TABIL, L.G., PANIGRAHI, S., CRERAR, W.J., The influence of fiber content on properties of injection molded flax fiber-HDPE biocomposites, Can. Biosyst. Eng., 08(148), 2009, p. 1–10.

3.CANTERO, G., ARBELAIZ, A., LLANO-PONTE, R., MONDRAGON, I., Effects of fibre treatment on wettability and mechanical behaviour of flax/polypropylene composites, Compos. Sci. Tech., 63, 2003, p. 1247–1255.

4.MALKAPURAM, R., KUMAR, V., YUVRAJ, S.N., Recent development in natural fibre reinforced polypropylene composites, J. Reinf. Plast. Compos., 28, 2008, p. 1169–1189.

5.MOHANTY, A.K., MISRA, M., HINRICHSEN, G., Biofibers, biodegradable polymers and biocomposites: an overview, Macromol. Mater. Eng., 276-277, 2000, p. 1–24.

6.NABI SAHEB, D., JOG, J.P., Natural fiber polymer composites: a review, Adv. Polym. Technol., 18, 1999, p. 351.

7.ROWELL, R.M., SANADI, A.R., CAULFIELD, D.F., JACOBSON, R.E., Utilization of natural fibers in plastic composites: Problems and

opportunities, Proc. First Int. Lignocellul. Compos. São Paulo, 1996, p. 23–52.
8.WAMBUA, P., IVENS, J., VERPOEST, I., Natural fibres: can they replace glass in fibre reinforced plastics? Compos. Sci. Tech., 63, 2003, p. 1259–1264.
9.GAUTHIER, R., JOLY, C., COUPAS, A.C., GAUTHIER, H., ESCOUBES, M., Interfaces in polyolefin/cellulosic fiber composites: chemical coupling, morphology, correlation with adhesion and aging in moisture, Polym. Comp., 19, 1998, p. 287–300.
10.DE BRUIJN, J.C.M., Natural fibre mat thermoplastic products from a processor's point of view, Appl. Compos. Mater., 7, 2000, p. 415–20.
11.BROUWER, W.D., Natural fibre composites: Where can flax compete with glass? SAMPE J., 36, 2000, p. 18–23.
12.DHAKAL, H.N., ZHANG, Z.Y., RICARDSON, M.O.W., Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites, Compos. Sci. Technol., 67, 2007, p. 1674–1683.
13.AHMAD, I., BAHARUM, A., ABDULLAH, I., Effect of extrusion rate and fiber loading on mechanical properties of Twaron fiber-thermoplastic natural rubber (TPNR) composites, J. Reinf. Plast. Compos., 25, 2006, p. 957–965.
14.HAJNALKA, H., RACZ, I., ANANDJIWALA, R.D., Development of HEMP fibre reinforced polypropylene composites, J. Thermoplast. Compos. Mater., 21, 2008, p. 165–174.
15.LEE, B.H., KIM, H.J., YU, W.R., Fabrication of long and discontinuous natural fibre reinforced polypropylene biocomposites and their mechanical properties, Fiber. Polym., 10, 2009, p. 83–90.
16.LI, X., PANIGRAHI, S., TABIL, L.G., A study on flax fiber-reinforced polyethylene biocomposites, Appl. Eng. Agr., 25, 2009, p. 525–531.
17.PANIGRAHY, B.S., RANA, A., CHANG, P., PANIGRAHI, S., Overview of flax fibre reinforced thermoplastic composites, Can. Biosyst. Eng. J., 06-165, 2006, p. 1–12.
18.LOPEZ MANCHADO, M.A., ARROYA, M., BIAGIOTTI, J., KENNY, J.M., Enhancement of mechanical properties and interfacial adhesion of PP/EPDM/Flax Fibre Composites using maleic anhydride as a compatibilizer, J. Appl. Polym. Sci., 90, 2003, p. 2170–2178.
19.SANTOS, E.F., MAULER, R.S., NACHTIGALL, S.M.B., Effectiveness of maleated- and salinized-PP for coir fiber-filled composites, J. Reinf. Plast. Compos., 28, 2009, p. 2119–2129.
20.KU, H., WANG, H., PATTARACHAIYAKOOP, N., TRADA, M., A review on the tensile properties of natural fibre reinforced polymer composite, Compos. Part B-Engineering, 42, 2011, p. 856–873.
21.KORONIS, G., SILVA, A., FONTUL, M., Green composites: A review of adequate materials for automotive apllications, Compos. Part B-Engineering, 44, 2013, p. 120–127.
22.KABIR, M.M., WANG, H., LAU, K.T., CARDONA, F., Chemical treatments on plant-based natural fibre reinforced polimer composite: An overview, Compos. Part B-Engineering, 43, 2012, p. 2883–2892.
23.MEI-PO, H., WANG, H., JOONG-HEE, L., KIN-TAK, L., JINSONG, L., HUI, D., Critical factors on manufacturing processes of natural fibre composites, Compos. Part B-Engineering, 43, 2012, p. 3549–3562.
24.HOI-YAN, C., MEI-PO, H., KIN-TAK, L., CARDONA, F., HUI, D., Natural fibre-reinforced composites for bioengineering an enviromental engineering applications, Compos. Part B-Engineering, 40, 2009, p. 655–663.
25.UYAMA, H., KUWABARA, M., TSUJIMOTO, T., KOBAYASHI, S., Enzymatic synthesis and curing of biodegradable epoxide-containing polyesters from renewable resources, Biomacromolecules, 4, 2003, p. 211–215.
26.SHOGREN, R.L., PETROVIC, Z., LIU, Z.S., ERHAN, S.Z., Biodegradation behavior of some vegetable oil-based polymers, J. Polym. Env., 12, 2004, p. 173–178.
27.PRATI, S., SCIUTTO, G., MAZZEO, R., TORRI, C., FABBRI, D., Application of ATR-far-infrared spectroscopy to the analysis of natural resins, Anal. Bioanal. Chem., 399, 2011, p. 3081–3091.
28.SUPRAKAS, S.R., MOSTO, B., Biodegradable polymers and their layered silicate nanocomposites: in greening the 21st century materials world, Prog. Mater. Sci., 50, 2005, p. 962–1079.

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