Mechanical Behaviour Evaluation of Arboform Material Samples by Bending Deflection Test

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The low biodegradability of petroleum-based plastic materials led to the search for novel biodegradable plastics. In this way, a team of German researchers developed, produced and marketed a material that can help the environment, in terms of 100% biodegradability and renewability, contributing to a more efficient use of resources. The trade name proposed by the team is "liquid wood" and is a high-quality thermoplastic material. It brings together the wood and plastics processing industries, in order to make products with complex design geometry and to process warm material wood (lignin and natural fibers) using the same technique and equipments just like for conventional thermoplastic materials. This paper presents analyses of bending test behavior in case of Arboform L, V3 Nature -"liquid wood" (A-LW) and Arboform reinforced with Aramid Fibers (A-LWAF). The results were compared with technical literature and some plastic materials in case of requirement for greater stiffness of material.

Keywords: bending test, Arboform, bending strength, flexural modulus

With the passing years, as we become more technologically advanced, high performance plastic materials are produced, which withstand at extreme conditions (high temperatures, rain, frost and others), are durable and easy to use. But these advanced products made from nonrenewable natural resources, fossil materials like coal, oil, gas do not break down naturally, plastic pollution becoming this way a global issue. Solving this problem, by creating synergies between the use of renewable resources, environmental protection and development of biodegradable innovative materials became an immediate priority, [1, 2]. Biodegradable materials are one of the most dynamic and perspective fields with applications in all industrial areas. The development and market of a new multifunctional material based on renewable resources with outstanding performances in terms of physical, mechanical, thermal, structural, electrical and structural properties, durability, maintenance and cost preoccupied also a team of German researchers. The material is a mixture of 30% lignin (the matrix of the material - waste from the paper making process) with 60% annual plant fibers and wood particles (flex, hemp, sisal, wood fibers or others plant fibers) and 10% natural additives (processing aids, impact modifier, flame retardants that improve the material rheology). Their product is commercially known as "Liquid wood"- Arboform, [1].

Arboform is a new granular thermoplastic material, which can be processed at raised temperatures just like any other thermoplastic material by injection moulding, extrusion, calendaring, deep drawing or pressing using the same processing equipments, [3]. Experimental research was focused on Arboform L, V3 Nature (A-LW) and Arboform L, V3 Nature reinforced with Aramid Fibers (A-LWAF).

The disposal of "liquid wood" parts at the end of the life cycle is done as for naturally grown wood. It can be done by natural decay in three main components water, humus and carbon dioxide or by incineration, the amount of pollutant emitted, CO_2, being the same amount consumed from the atmosphere by the plants during their growth, [1].

Experimental part

The experimental study plan used in this research is the Taguchi methodology. The method satisfies some criteria like the minimization of the tests number this leading to decreased price of the experimentation, and to provide the best possible accuracy.

A simple model of matrix which comprises "i" factors noted from F_1, F_2, … to F_i was proposed by Viger and Sisson's system. In the present study six factors, technological parameters, are used: T_{melt} - melt temperature, [^oC]; t_{inj} - injection time, [s], t_c - cooling time, [s], S_d - screw displacement, [mm], P_{inj} - injection pressure, [MPa] and D_{inj} - angle injection in the mold, [^{o}]. Each factor has n_i levels of variations (table 1 and table 2). For experiments validation, three identical specimens are performed. The coefficients of a type (1) model were determined in the experimental study, [4]. In equation (1) the general average was noted with M.

Following experiments, it was observed that injection pressure has the greatest influence on the process. Two other significant influence parameters are melting temperature and injection direction. Screw speed,

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Input parameter	T_{melt} [°C]	t_{inj} [s]	t_c [s]	S_d [mm]	P_{inj} [MPa]	D_{inj} [°]
Ist level	150	9	18	60	80	0
IInd level	160	11	25	80	100	90

Table 1
TECHNOLOGICAL PARAMETERS VARIATION DURING A-LW INJECTION

Input parameter	T_{melt} [°C]	t_{inj} [s]	t_c [s]	S_d [mm]	P_{inj} [MPa]	D_{inj} [°]
Ist level	165	10	25	70	120	0
IInd level	175	15	35	90	140	90

Table 2
TECHNOLOGICAL PARAMETERS VARIATION DURING A-LWAF INJECTION

injection time and cooling time, are less significant, [4]. After the orthogonal and number of freedom degrees conditions were analysed, 16 experimental tests have been performed.

The experiments were performed in the Technology and processing Systems Laboratory, Department of Industrial Engineering, “Tor Vergata” University of Rome, Italy.

Three point bending test

Due to the necessity of high quality, reliability and biodegradability plastic materials, bending test method became an important test in terms of manufacturing process, research and development. The method defines the ability of unidirectional composite materials

$$Z_T = M + T_{melt} + t_{inj} + t_c + S_d + P_{inj} + D_{inj} + P_{inj}T_{melt} + P_{inj}t_{inj} + P_{inj}t_c + P_{inj}S_d + P_{inj}D_{inj} \quad (1)$$

to resist under load (compression). From the three - point bending test, the values about the texural stiffness and strength properties of the material can be extracted [5].

The flexural stress can be calculated using equation (2), [5].

$$\sigma_f = stress = \frac{M \cdot c}{I} \quad (2)$$

where M is maximum bending moment, c represents the distance from center of sample.

Equation (3) expresses the relation of flexural strain, symbolic noted e_f, [5]:

$$\varepsilon_f = \frac{6Dh}{L^2} \quad (3)$$

One of the important characteristics, specific of solid materials, is the Young’s modulus (modulus of elasticity). For polymer composites the flexural modulus E_f, it is given by the equation (4), [5]:

$$E_f = \frac{L^3 m}{4bh^3} \quad (4)$$

In the above equations the following parameters were used: σ_f - stress [MPa], ε_f - strain [%], E_f - Young‘s Modulus [MPa], L - distance between pins [mm], b - sample width [mm], h - sample depth [mm], D - maximum deflection in the midle of sample [mm], m - slope [N/mm].

The dimensions of the samples used in case of this mechanical test are length 80mm, width 10mm and thickness 4mm, according to ISO 178, [6].

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This test method utilizes a system with load in three points which is applied to a simply supported sample. Tests were conducted using MTS Insight 5 equipment adapted for bending test (fig. 1). The machine has Test Work4-MTS Erica Flexural software.

In this test a specimen with rectangular cross-section (10.1x4mm) is placed on two parallel supporting pins with the diameter of 5mm placed at 60mm one from each other.

The loading force (F) is applied in the middle by means of the loading pin, having an initial load of 5N (fig. 2).

The speed test used was 1 mm/min. The bending tests were performed at room temperature (RT=23°C).

Fig.1 Bending test equipment during the bending test

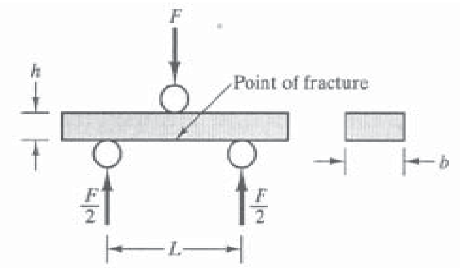

Fig. 2 Three point bending test method, [5]

The pins and loading supporting are fixed such that allow their free rotation about axis parallel to the specimen axis and axis parallel to the pin axis. In this way a uniform loading of the specimen is provided, friction between the supporting pins and the specimen being prevented.

The mean values obtained according to the experimental design for bending test, in case of the materials studied in this paper, A-LW and the A-LWAF are presented in table 3.

Results and discussions

After testing can be observed that the material, A-LW, records the highest flexural strength at testing number 14 and the value is 2.3MPa, (fig. 3). Three samples for flexural test were used (1, 2, 3 curves for samples used). Its value is influenced by the injection temperature, the angle injection and injection pressure. In case of 0^0 angle injection the values are higher than 90^0 injection angle (fig. 4).

The modulus of elasticity can be determined after what bending test was carried out. In the experimental research the average is 5.72GPa and 6.74GPa maximum value recorded (fig. 5).

According to the results the average for flexural strength in those sixteen tests (fig. 8) is approximately 0.72MPa. After testing, A-LWAF, records the highest flexural strength at testing number 10 (0.92 MPa) (fig. 7).

Table 3
BENDING TEST RESULTS OF "LIQUID WOOD" SAMPLES

	A-LW				A-LWAF			
No. exp.	ε_f [%]	σ_f [MPa]	E_f [MPa]	ρ [g/cm^3]	ε_f [%]	σ_f [MPa]	E_f [MPa]	ρ [g/cm^3]
1	0.35	0.94	5343.47	1.3617	2.48	0.81	6669.19	1.25
2	0.32	0.89	5252.25	1.2465	1.66	0.56	6213.98	1.28
3	0.58	1.85	6264.72	1.2276	2.53	0.77	7051.88	1.29
4	0.31	0.91	5315.54	1.2658	1.95	0.64	6202.95	1.28
5	0.41	1.31	6256.06	1.2028	2.52	0.80	6745.24	1.26
6	0.46	1.20	5037.86	1.2833	1.39	0.48	5820.62	1.29
7	0.62	2.00	6414.20	1.2664	2.82	0.85	7060.85	1.28
8	0.50	1.33	4970.75	1.1815	1.20	0.65	4204.01	1.26
9	0.65	2.02	6219.55	1.1325	2.85	0.92	6834.10	1.28
10	0.68	1.84	5136.35	1.1140	1.88	0.73	5711.52	1.26
11	0.45	1.54	6739.84	1.2587	2.38	0.74	6870.60	1.28
12	0.65	1.83	5464.63	1.1864	1.77	0.60	5797.34	1.27
13	0.70	1.93	5681.83	1.2676	2.47	0.85	6211.23	1.27
14	0.72	2.30	6591.78	1.2523	2.44	0.78	6697.04	1.26
15	0.44	1.24	5427.68	1.2783	1.98	0.62	6565.91	1.27
16	0.68	1.91	5444.83	1.2691	2.48	0.81	6669.19	1.25

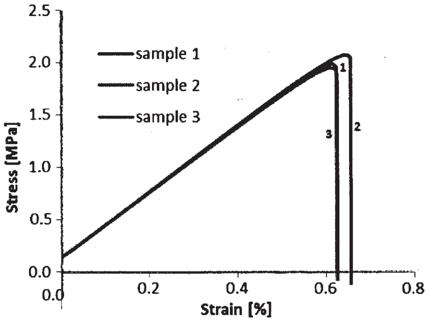

Fig. 3 Stress – strain diagram, exp. no. 14

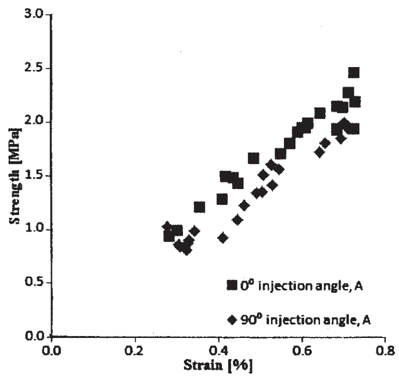

Fig. 4 A-LW bending test results

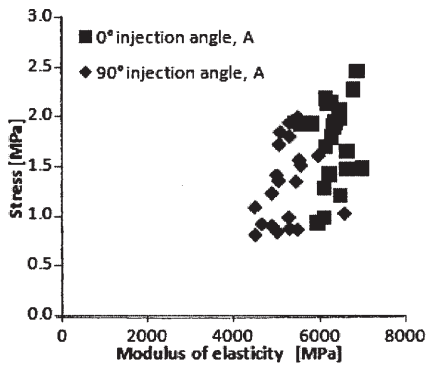

Fig. 5. Modulus of elasticity of A-LW

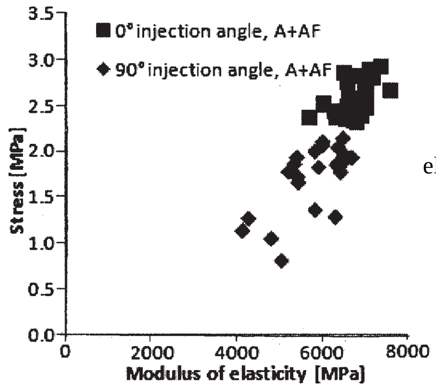

Fig. 6. Modulus of elasticity of A-LWAF

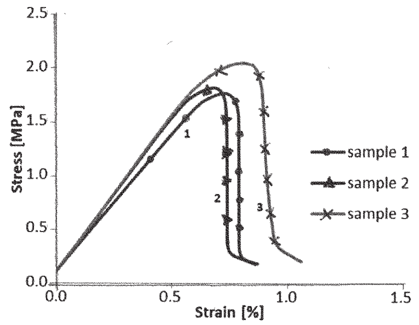

Fig. 7. A-LWAF stress - strain

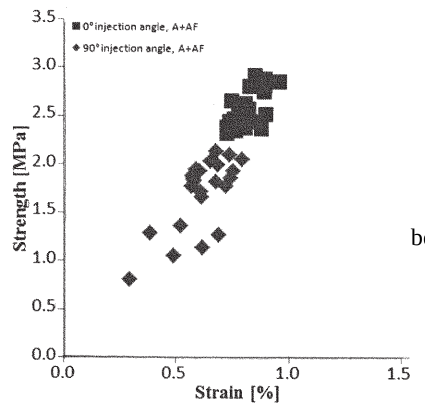

Fig.8 A-LWAF bending test results

For the Young's modulus (fig. 6), the average is 6.2GPa and the maximum value recorded 7GPa.

After bending test of both materials were found that both values of flexural strength and elastic modulus are higher for material reinforced with 30% Aramid Fibers (TWARON D1088 type), as it can be seen in figure 9 and figure 10.

Also the samples at 0° angle injection especially for A-LWAF present the highest values in terms of flexural strength and Young's modulus.

In terms of materials density for the values obtained, it can be concluded (fig.11), that their density does not suffer major variations after successive changes of input parameters and the material resistance is not influenced.

The values of the elasticity modulus obtained were compared with some plastics values, [7]. Thus, these two materials can replace a few plastic materials such as: PA 66 (Polyamide); PA11 (Polyamide); POM (Acetal Homo-polymer); PE-HD (High Density Polyethylene); PVDF (Poly Vinylidene Fluoride); ECTFE (Etylene Copolymer) and others, if greater material stiffness is required. If low stiffness is required, the Arboform L,V3 Nature and the reinforced material can replace the

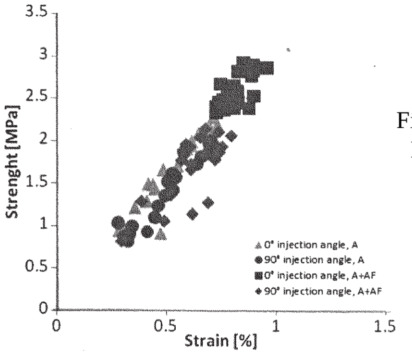

Fig. 9 Arboform vs. A-LWAF, bending test results

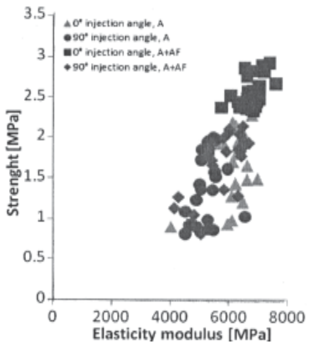

Fig. 10 A-LW vs. A-LWAF, Young modulus

following plastics: PPS GF 40 (Poly Phenylene Sulphide with 40% glass fiber), PA 66CF20 (Polyamide black, 20% carbon fibre black); PEEK GF30 (Poly Ether Ether Ketone with 30% Glass Fiber) and other plastic materials, [7].

Finally, we can say that these „green“ materials can be used in many areas of industry in obtaining cars interior, technical parts, watch cases, toys, loudspeakers, small coffins and others parts.

The standard theories in biocomposite materials are based on the property of differentiability of dynamic variables. In such context, the models built are sophisticate and intensively customized [8-11]. In our opinion, the biocomposite materials can be assimilated with complex systems. From this point of view, an adequate model can be developed assuming that the structural units of the biocomposite materials have a motion on continuum but non-differentiable curves (fractal curves). More than this, both the deterministic and stochastic behaviors can be captured in the same formal framework (for details see [12-17]).

Conclusions

The study of the bending test of A-LW is motivated by the rapid expansion of composite materials, in a great measure in industrial applications. A-LW and in particular, A-LWAF need detailed analysis due to the inexistent results regarding their mechanical (flexural properties) behavior.

The experimental results obtained in terms of bending test reveals great potential of A-LW and A-LWAF, making them possible to replace numerous plastic materials (PE-HD, PEEK GF 30, PA66, PVDF, PPS GF 40, ECTFE, POM, PEI GF 30 and others) from the point of view of bending property and not only.

After bending test, it can be noted that the A-LW presents a more brittle behavior than the A-LWAF. This remark can be seen in the stress – strain diagrams. Young's modulus in case of A-LW reaches 6.74GPa and for the reinforced material is 7GPa, these values being closely linked with the relation between the fibers and the matrix stiffness. The reinforcement of the A-LW with Aramid Fiber visibly increases the mechanical

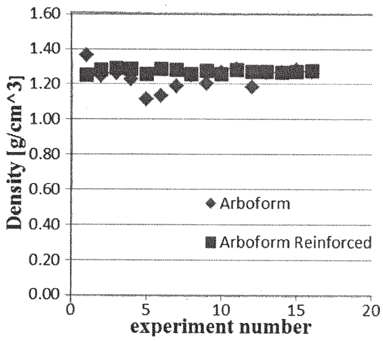

Fig. 11 Density of tested materials: -A-LW; -A-LWAF

properties of the „liquid wood“. Other improvements are given by the injection parameters used especially by injection pressure, melting pressure and angle injection.

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