

Valuation Of The Sawdust Stemming From Moroccan Cedrus Atlantica By Introducing It As Charge Into A Matrix Of High-Density Polyethylene

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Abstract: The introduction of the sawdust stemming from the cedar of Atlas as a reinforcement in a matrix plastic to produce a wood plastic composite have been studied. The tensile properties of composites established of sawdust in a matrix of high-density polyethylene (PEHD) were measured; five mass concentrations and three size grades were studied, with the presence of a coupling agent (Maleic anhydride grafted polyethylene, PE-g-MA). The presence of sawdust in the polymeric matrix modifies considerably his mechanical properties, the composite loses in ductility and in tenacity, but its rigidity increases. The tensile strength is lesser than those obtained with the only polymer. The best mechanical properties were obtained with the fine sawdust which can be likened to the wooden floor. It is for the 5 % content that the highest tensile strength was observed and for a 20 % content that the highest Young modulus was recorded.

Index Terms: cedrus atlantica, valuation, wood, plastic, sawdust

1 INTRODUCTION

The waste recycling affects several domains of interest such as the environmental protection, the industry, the economy, and the society, therefore, it is an essential actor of the sustainable development[1]. For more than a decade, composites established of thermoplastic matrix knew an important industrial development and have attracted big interests for fundamental research [2]–[4]. Potential applications of these composites are in the domains of building materials, furniture and automotive industry [5]. Owing to the high prices of oil-related products[2], [3], composite established of a matrix in polymer and reinforcement in synthetic fiber, such as carbon fiber and fiber glass pulled in an important way the interest of the industrialists, due to their excellent mechanical performances[6]. Nevertheless, as this type of reinforcement is non-degradable and poorly recyclable, it represents a significant impact on the environment [7]. Hence, many efforts were supplied by the researchers to develop polymeric composites with natural fibers, several types of natural fillers have been studied, due to their numerous advantages: environmental friendliness [8], low cost, low-density, higher specific strength, a higher modulus of elasticity [4]. Ayilimis et al. [9] investigated the potential use of the decayed wood in thermoplastic composites as reinforcing filler, and Istrate et al. [10] studied the structure and properties of clay, recycled plastic composites. Big interest of researches had been focalized on the effects of introducing wood in polymers as reinforcement on the physical properties of the composites, Migneault et al.[11] studied the effect of fiber origin, proportion, and chemical composition on the mechanical and physical properties of wood-plastic composites; they found that mechanical strength increased with increasing fiber proportion. Bouafif et al.[12] studied the

effects of fiber characteristics on the physical and mechanical properties of wood plastic composites; they demonstrated that the flexural modulus of elasticity showed a steady increase with increasing particle size. And Yang et al.[13] had working on the optimization of material composition to improve physical properties of wood-plastic composites; they proved that wood plastic composites manufactured with finer wood flour particles provided superior physical and mechanical performances. There are several techniques of manufacturing these composite materials such as the injection molding and the extrusion [14]. The fillers are present in the composite in the form of fibers [15], in the form of flour[16] or in the form of sawdust[17], in dimension enough fine to allow a shaping by standard processes, such as the extrusion[13] or the injection molding[2]. However, there is an incompatibility between the reinforcement (wood) which is hydrophilic and the matrix thermoplastic which is hydrophobic, this result in a weak joining between both phases, difficulties to obtain a homogeneous mixture, problem of conglomeration of the wood and disappointing mechanical properties [18]. An improvement of the mechanical resistance requires a better link between the compounds of the composite. It can be obtained by a chemical modification of the surface of the wood or the matrix [15], Or by the addition of a coupling agent whose role is to establish a bridge between compounds. Moreover, this agent also plays the role of dispersing agent and facilitates largely the obtaining of a homogeneous mixture to the molten state [19].

The final mechanical properties of composites Wood - polymers are depends on the properties of the matrix and of the reinforcement, of the concentration of the reinforcement [13], of its geometry, of the concentration of the coupling agent [18], and also the conditions of the manufacturing [20]. The efficiency of the mixture is necessary to insure a good dispersal of the wood in the matrix [20]. A fine mixture of the constituents can be obtained by convenient manufacturing process [19], [21]. The purpose of this study is to value the wooden sawdust stemming from Moroccan Cedrus Atlantica by introducing it as reinforcement into a matrix PEHD, for its abundance in nature and its wake impact on the environment since it is natural and biodegradable. The Atlas Cedar is present by an unequal importance in north Africa, especially in

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Morocco, 130 000 ha in the Moroccan Atlas and 15 000 ha in Rif [22]. Besides, The woode industry has a considerable economic importance for Morocco (more than 300 000 m³/year) [23], This activity generates a colossal quantity of sawdust, which represent 10 % of the volume of wood transformed by sawmills[23], it means that a minimum of 30 000 m³ of sawdust is generated in Morocco every year. The waste of sawmills can find outlets towards the industries of trituration (paper pulp, particle panel). however, most of the residues are traditionally used as a fuel, agents for cleaning of the industrial building, the litter for the poultry or the cattle[23]. Moreover, the effects of the rate and the size grade of the sawdust on the mechanical properties of the composite Cedar-PEHD were investigated in this paper..

2 MATERIALS AND METHODS

2.1 Materials

The polymeric matrix is a high-density polyethylene (PEHD) was supplied by ExxonMobil; It has a peak melting temperature of 133°C, a heat deflection temperature at 0.45 MPa of 64 °C, a density of 0.956 g.cm⁻³, and a melt index of 20 g/10 min [24]. The wood is in the form of sieved sawdust, this sawdust was obtained from traditional workshop joinery in the region of Azrou Morocco, It is mainly constituted by the wood of the cedar (*Cedrus Atlantica*). The coupling agent used in this study is the Maleic anhydride grafted high-density polyethylene; it was purchased from Sigma-Aldrich Ireland Ltd, It has a peak melting temperature of 107°C, and a viscosity of 500 cP (140°C) [25], we were using a fixed quantity of 3 wt.% in all composites samples, this concentration was found to be optimal for increasing the Young's modulus for Wood/Polymer composites [26], [27].

2.2 Composite compounding and characterization techniques

Sawdust was dried in one steam room in 83°C for 48 hours, and left in the steam to cool to room temperature, then preserved in bags in polyethylene until their use. Sawdust was sieved to obtain three sizes grading according to the diameter of sieves: <125 µm; 125-200 µm; 200-335 µm (Figure. 1).



Figure 1. Cedrus sawdust with three size grade (a) <125µm, (b) 125-200µm, (c) 200-335µm

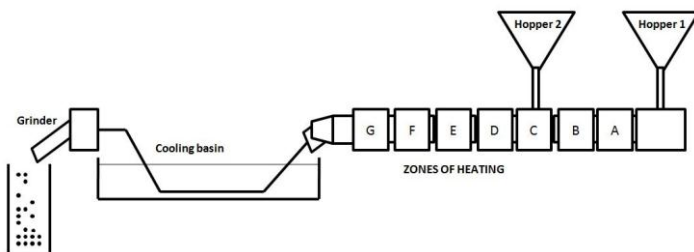


Figure 2. Melt extruder process

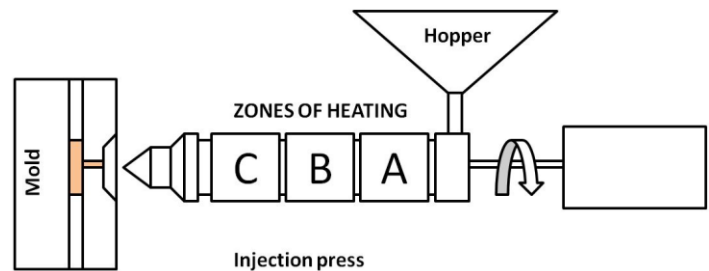
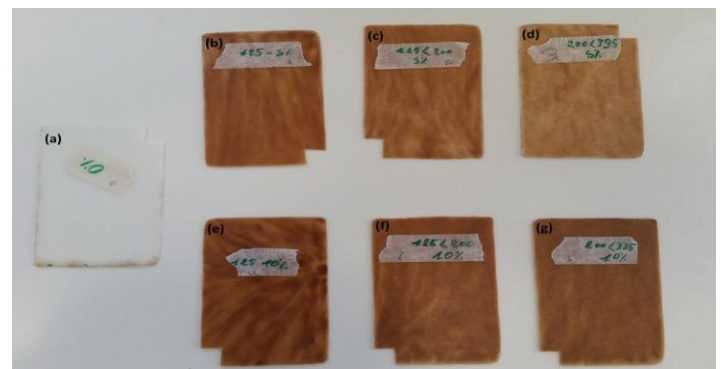


Figure 3. Injection molding process

Five contents of *Cedrus Atlantica* Sawdust in the HDPE matrix (0, 5, 10, 15, 20 wt.%) with 3 wt.% of the coupling agent were made in two stages, in the first stage; the composites were melt-blended simultaneously with a twin-screw extruder (Leistritz Extrusions technik GmbH, Germany). Mixing was performed with a temperature profile of 170/170/175/180/180/175/170 °C, 170 °C for die temperature (Figure. 2), and a rotating speed of 125 rpm for the main screws and 40 rpm side-feeder screw. After being cooled in a bath of water, the mixtures were pelletized into granules of 2 mm in length. In the second stage, the granules were transformed to panels in an injection molding machine (Engel e-Victory), during the injection molding, the temperature in the screw chamber was fixed at 180°C in the three zones, the nozzle was at the temperature of 170°C, and the mold at 40°C (Figure. 3) [28].

2.3 Tensile tests

Six samples were continuously requested in tensile stress until ruptured for each of the composites, the averages were taken as representative values, The specimens (Figure. 4) were tested 10 days after their manufacturing, They were preserved and tested in ambient conditions (about 25 °C and 45% of relative humidity). We used a machine of universal drive Instron 8821s with a cell of load of 5 kN. The speed of the test is 5 mm/min, which assures a break of the composite between 30 seconds and 2 minutes, in compliance with the standard ISO 527-1:2012 (Figure. 5). The curve obtained constraint / deformation is visible, because it is the initial geometry of the specimen that is used in the calculations. However, for our composites, the true constraints are little different from visible constraints because the plastic deformations are very weak (less than 5 %) and because there is of no striction before the break. The module of Young is Estimated by the secant method (in 0 and 0,1 % of total deformation).



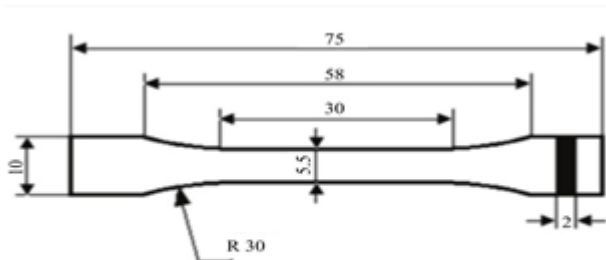


Figure 5. Tensile test specimen

3 RESULTS AND DISCUSSION

The obtained strain-stress curves of the neat HDPE and the composites are shown in Figure. 6, it demonstrates the behavior of all composites under the same mechanical solicitation, we can see that the composite becomes stiffer and more elastic with the rise of the wood content, the neat HDPE has a maximum plastic behavior, and the composite with 20% of wood was the more elastic one, this results are owing to the reduction of the plastic energy of the material. In general, there is a good improvement in the material's rigidity with the increase in the wood content; however, there is a drop in ductility. Tables. 1, 2 and 3, Synthesizes the results of traction tests, respectively, for composites with fine, medium and coarse sawdust.

Table 1 Mechanical properties of composites with fine sawdust

Sawdust rate	E(Mpa)	Rm(Mpa)	Rp(Mpa)	$\epsilon R(\%)$	W(N.mm)
0%	945	14,12	25,64	132,12	7005
5%	1009	14,99	25,81	80,12	6032
10%	1653	14,13	25,51	60,21	4136
15%	1802	13,56	24,93	24,23	2003
20%	2009	12,80	24,51	5,63	1890

Table 2 Mechanical properties of composites with medium sawdust

Sawdust rate	E(Mpa)	Rm(Mpa)	Rp(Mpa)	$\epsilon R(\%)$	W(N.mm)
0%	945	14,12	25,64	132,12	7005
5%	970	13,89	25,41	68,12	5732
10%	1309	11,33	24,83	53,21	3966
15%	1675	11,06	24,43	19,23	1928
20%	1894	10,82	24,16	5,43	1857

Table 3 Mechanical properties of composites with coarse sawdust

Sawdust rate	E Mpa	Rm Mpa	Rp Mpa	ϵR %	W N.mm
0%	945	14,12	25,64	132,12	7005
5%	947	12,59	25,11	61,12	5443
10%	1137	10,96	24,63	48,21	3816
15%	1357	10,13	24,03	11,23	1899
20%	1552	9,82	23,86	4,43	1842

The indicated parameters are modulus of elasticity (Young's modulus) E, offset yield strength at 0,2 % Rp, tensile strength Rm, strain to fracture ϵR , Area under the curve from the origin to the maximum of the curve W, This last parameter is an indicator of the tenacity of the material (after, W is calculated

on the raw curve strength/displacement, what explains that the corresponding unit is expressed in N.mm).

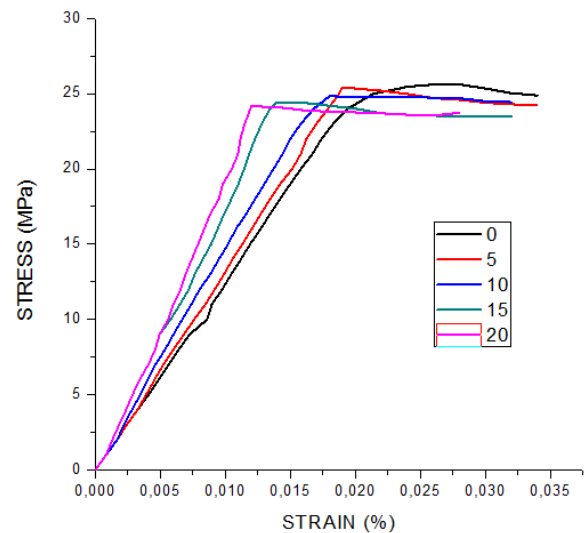


Figure 6. Tensile stress–strain curves of HDPE–wood flour composites

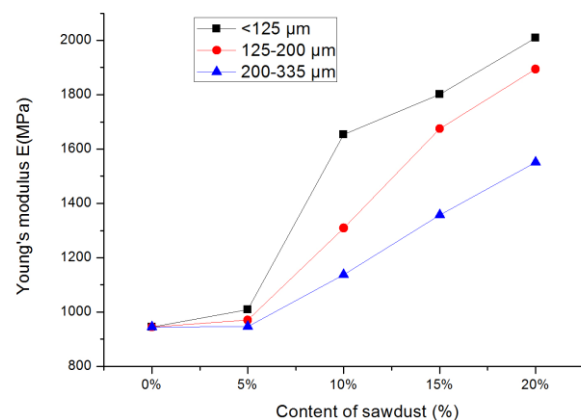


Figure 7 Young modulus / against content of sawdust with various *Cedrus Atlantica* sizes

The module of Young is an increasing function of the content in sawdust Figure 7, The results are rather little different between medium and coarse sawdust, What is in compliance with the fact that size grading are relatively close, Globally, the module decreases with the increase of the average size of sawdust. Modules with fine sawdust are very widely superior to the module of the matrix, Which is 945 MPa, The biggest rigidity (2009 MPa) Is obtained in 20 wt.% of fine sawdust. This decrease of the rigidity of the composite is due to the rigidity of the *Cedrus atlantica* wood, These results are in agreement with those of the literature:[16][29][30][21].

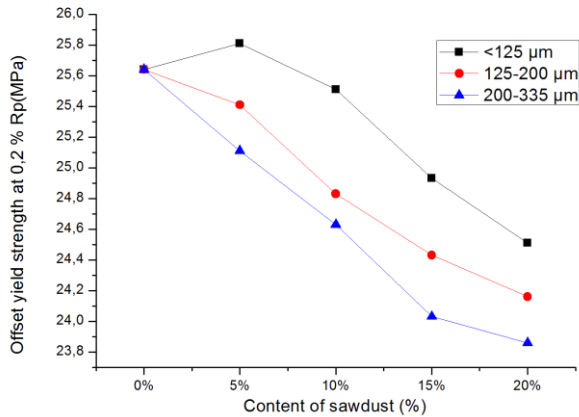


Figure 8 Offset yield strength / against content of sawdust with various Cedrus Atlantica sizes

For the elastic limit R_p Fig. 2 (b), and for fine sawdust, we noticed an optimum at a concentration of 5 wt.% sawdust, with an increase in the value of the mechanical resistance of 0.66% compared to the virgin resin, it can be explained by the strong bonding between wood and HDPE due to the high contact surface between the phases, and also the positive effect of the coupling agent which leads to a good adhesion. However, for concentrations greater than 5 wt.%, the offset yield strength drops intently up to a value lower than the virgin resin resistance with a percentage of 4.40% with a level of 20% of fine sawdust. For the elastic limit R_p Fig. 2 (b), and for fine sawdust, we noticed an optimum at a concentration of 5 wt.% sawdust, with an increase in the value of the mechanical resistance of 0.66% compared to the virgin resin, it can be explained by the strong bonding between wood and HDPE due to the high contact surface between the phases, and also the positive effect of the coupling agent which leads to a good adhesion.

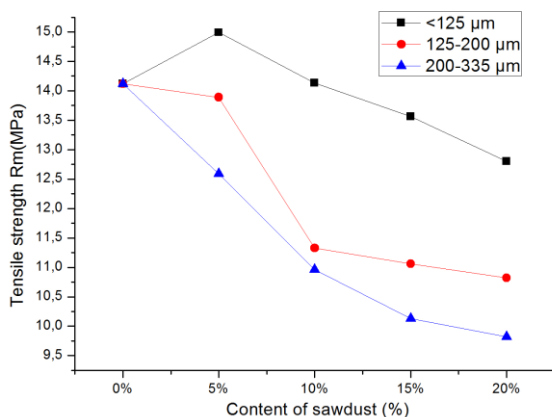


Figure 9 Tensile strength / against content of sawdust with various Cedrus Atlantica size

However, for concentrations greater than 5 wt.%, the offset yield strength drops intently up to a value lower than the virgin resin resistance with a percentage of 4.40% with a level of 20% fine sawdust. For the tensile strength of the material Fig. 2(c) the results show that its value increases in a slightly noticeable way for the 5 wt.% content (6,16%), and to a lesser

extent with 10 wt.% in sawdust (0,071%), Besides, above 10 wt.%, the tensile strength decrease cause of the formation of agglomeration, leading to feeble interfacial adhesion between wood and polymer, the increment in contact surface engender decohesion between the two phases. Furthermore, in the case of medium and coarse sawdust, the values of the tensile strength are decreasing according to the sawdust content. The increase of E and R_m is particularly important with fine sawdust, these parameters are all increased by at least 50 % compared with average and coarse sawdust. This effect can be attributed to the area/volume ratio, which is significantly higher with fine sawdust Table 1, The specific contact surface being larger, the chemical bonds through the coupling agent to the wood - polymer interface are more numerous. This could explain the fact that mechanical properties decrease with increasing average sawdust size. This argument is the one generally advanced by the authors who have characterized the influence of particle size on the mechanical properties of wood-polymer composites. [20][31][13]

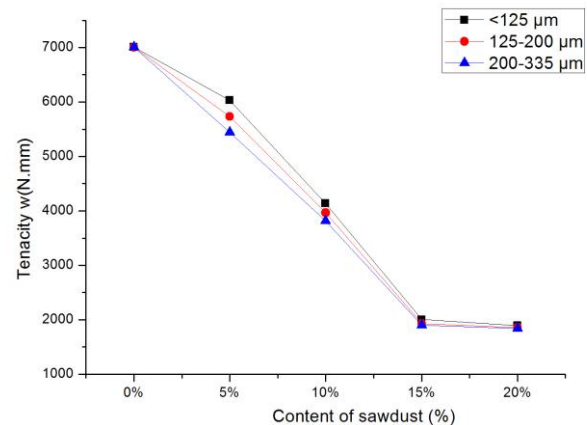


Figure 10 Tenacity / against content of sawdust with various Cedrus Atlantica size

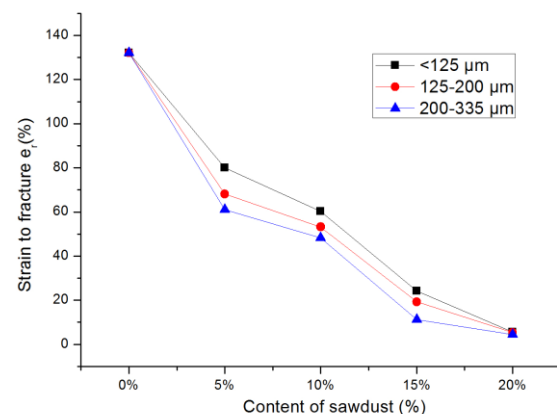


Figure 11 Strain to fracture / against content of sawdust with various Cedrus Atlantica size

In all cases, the presence of sawdust significantly reduces ductility Fig. 2(d) and, concomitantly, the tenacity Fig. 2(e). A dramatic drop with the grade and particle size of sawdust has been noticed at the level of ductility. For three size grading, the tenacity decreases in a very similar way with the increase of the content in sawdust. The best tenacity is obtained with the

lowest content in fine sawdust, it corresponds to 86 % of the tenacity of the PEHD. These tendencies are to be moved closer to the morphology of the reinforcements.

4 CONCLUSION

The exploitation of Moroccan natural resources as reinforcement in wood-plastic composites can be considered as a very promising idea and as an ecological topic of research, due to the improvement of some mechanical properties of the material, and to the economic and environmental benefits that can give, numerous industrial domains can take benefit from this composite material. This study investigated the valuation of the sawdust from the cedar of the region of the Atlas " *Cedrus Atlantica* " by introducing it as charge into a matrix of high-density polyethylene. The addition of the sawdust improves clearly the rigidity of the composite; the results show that Young modulus increase according to the content in sawdust for the three used size grad. The tensile strength increases for the fine sawdust with the 5 and 10 % rates in sawdust for the medium and coarse particle size, the tensile strength is a decreasing function. In every case the ductility and the tenacity decrease with the increase of the content in sawdust. The best mechanical properties obtained with fine sawdust are most probably due to a better report surface / volume of the reinforcement allowing a better adhesion between the charge and the matrix.

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