



ISSN NO. 2320-5407

Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/8096
DOI URL: <http://dx.doi.org/10.21474/IJAR01/8096>



INTERNATIONAL JOURNAL OF
ADVANCED RESEARCH (IJAR)
ISSN 2320-5407
Journal Homepage: <http://www.journalijar.com>
Journal DOI:10.21474/IJAR01

RESEARCH ARTICLE

RESISTANCE OF WOOD PLASTIC COMPOSITE PRODUCED BY EXTRUSION AND COMPRESSION AGAINST THE FUNGI XYLOPHAGES *POSTIA PLACENTA* AND *TRAMETES VERSICOLOR*.

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Manuscript Info

Manuscript History

Received: 12 September 2018
Final Accepted: 14 October 2018
Published: November 2018

Keywords:-

resistance, dimensional stability, loss of mass.

Abstract

Wood plastic composite constitute compounds of great demand like materials. Biological agents are one of the main causes of the deterioration of wood and its derivatives. Creating materials more resistant to these agents is an important task for the forestry industry. The objective of this research was to evaluate the resistance of wood plastic composite to the fungi xylophages *Postia placenta* and *Trametes versicolor*. The boards were obtained by means of two treatments (1-extrusion and 2-compression), was used *Pinus caribaea* wood, thermoplastic polyethylene terephthalate, and calcium carbonate in proportions of 50-45-5. The loss of mass and dimensional stability in relation to thickness swelling was evaluated. This methodology carried out according to the American Society for Testing and Materials D 2017-81. Treatment 1 was classified as highly resistant, with mass loss of 6.41% for *Postia placenta* and dimensional stability of 3.75%, for *Trametes versicolor* it showed 4.15% mass loss, and 2.83% stability. The density of the board was affected in a measure of 20% for *Postia placenta*, and 23% for *Trametes versicolor*. Treatment 2 was classified as resistant, with 12% mass loss for *Postia placenta*, and 5.4% dimensional stability, for *Trametes versicolor* showed 10% mass loss and 4.6% dimensional stability. The density was affected in 30% for *Postia placenta* and 35% for *Trametes versicolor*. In relation to the controls, the density was affected in 8% for the treatment 1 and 10% for the treatment 2. The study provides new work aiming modifications of raw material to improve the board resistance.

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Introduction:-

Wood plastic composite are materials formed in two phases, a continuous plastic called a matrix that includes thermoplastics and another reinforcement or filling made of wood fiber or other lignocellulosic materials (Horta et al., 2017). The wood fibers are distributed randomly within the matrix of plastic materials, used to give body to the

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product. The percentage of wood fibers varies depending on the product, from 50% and even higher percentage, to the recycled plastic products that do not contain wood fibers (Martínez et al., 2014).

According to Chaudemanchet et al. (2018), wood plastic products are less rigid than solid wood, their mechanical strength is also less, and they deform when subjected to loads, soften under the action of heat and are brittle at low temperatures. Its resistance to traction and compression are similar to that of coniferous wood. However, the physical properties of these boards are superior to wood in weather conditions, these can be used in those applications that require greater rigidity, such as in the terraces of outdoor terraces, for this it is advisable to increase the cross section or its thickness or reduce the distance between supports.

Although warping does not occur and moisture absorption is lower than that of solid wood, the action of the sun tends to obscure the reason why it is usually light gray. Generally, they are products that offer resistance against the attack of fungi, xylophages insects of the larval cycle, termites and marine xylophages. However, they are not exempt from being attacked by such agents.

Some products incorporate protectors to prevent the appearance of molds and the growth of fungi, in the first prototypes for soils there were cubic decay, soft rot, fissures, fraying and weathering. For this reason, the study of the effect caused by these agents that deteriorate wood and wood products is an important reason for researcher's worldwide (Renner et al., 2010; Clemons, 2010).

The creation of materials resistant to these agents is the main problem for the wood industry, due to the need to use these materials in the open. Although the wood plastic composite are resistant, these fungi can influence their dimensional stability (water absorption and swelling), affecting their physical and mechanical properties, which is why studying such effects, contribute to create new materials more resistant and of higher quality (Hosseinhashemi and Badritala, 2017).

The factors that have the greatest influence on the development of fungi are humidity, temperature and the presence of air (oxygen). These conditions are conducive to the appearance of fungi *Postia placenta* Fr. Larsen & Lombard and *Trametes versicolor* L. Lloyd (Gonçalves et al., 2014).

According to Carrillo et al. (2011), humidity is of vital importance for the physiology of fungi. In the case of wood plastic composite, this factor is linked to the quality of the wood used in the production process, which must comply with the moisture parameter, particle size of the determined particles (Keskisaari and Kärki, 2018).

In spite of the diverse applications that these boards can provide for different purposes, few studies are related to their durability and resistance to the attack of biological agents. In this way, it is essential to evaluate the resistance of wood plastic composite to the attack of xylophages organisms, given its competition with the various conventional boards, which have a low natural durability (Paes et al., 2015).

In this study the resistance of wood plastic composite is evaluated, elaborated by means of two types of molding (extrusion and compression) before the effects that the fungi *Postia placenta* and *Trametes versicolor* can cause in their dimensional stability. The study makes it possible to assess the feasibility of using the dosages used against fungal attack, in addition to comparing these results with other studies carried out by several researchers on this type of panel. In this way, results can be obtained that allow us to see the usefulness and quality of this board in certain applications for construction and open new studies to find more suitable dosages to ensure greater resistance.

Material And Methods:-

Characteristics of the material

The wood plastic composite were obtained by extrusion and compression at laboratory scale, both in sawdust-thermoplastic-additive proportions of 50-45-5 (%). They were made from *Pinus caribaea var caribaea* wood as filling material, using particles between 1-6 mm and moisture content of 5%; Polyethylene terephthalate (PET) as thermoplastic matrix, basing the treatment thereof by washing and crushing into particles of 1-7 mm; and calcium carbonate (CaCO_3) as a chemical additive. The density of the board was $1,025 \text{ kg.m}^{-3}$ for boards obtained by extrusion and 920 kg.m^{-3} for those obtained by compression.

Extruded molding was performed by a single-screwed extruder with 7 mm screw diameter and 28:1 length to diameter ratio. The extruding temperature was between 160 and 170 °C, and the extruding speed was 0.7 - 0.8 m

min-1. The cross-section dimensions of the extruded samples were 250 x 6000 x 16 mm (width x length x thickness) for each treatment.

For the manufacture of the compression board, it was used as a urea-formaldehyde adhesive (MDP1021, diluted at 10%), with a solid content of 64%, a pH of 8.5, a viscosity of 371.86 and a density of 1.23 g.cm⁻³. The proportion of adhesive used was 10% in relation to the dry mass of the particles. Ammonium sulfate (NH₄)₂SO₄ at 24% was used, in proportion of 2% in relation to the total mass of solids, as a catalyst.

Compression molding allowed the mixing of the raw material by rotating drum with gluing system for the application of adhesive (10% in the particle of dry mass), later they were deposited in a box for the formation (50 cm x 50 cm of width and length) to shape the mattress square shape, then placed in the hot press, during the processing was used temperature of 180 °C, specific pressure of 70 kgf cm⁻² during a period of 18 minutes.

Four panels of 500 mm x 100 mm x 16 mm (length-width-thickness) were obtained, under the same raw material formulation, in each of them 5 specimens were randomly extracted with four repetitions totaling 20 evaluations for each fungus, totaling 80 test bodies plus 10 test bodies as a control used in the two types of board processing (extrusion and compression). The specimens were used with a dimension of 25 mm x 25 mm x 16 mm, corresponding to length, width and thickness. Figure 1 shows the method of extracting the specimens.

Entre Fig. 1

Experimental conditions

Used fungus causes brown rot (*Postia placenta* Fr. Larsen & Lombard) and white rot (*Trametes versicolor* L. Lloyd). They were grown on Malt Agar substrate according to the American Society for Testing and Materials: ASTM D-1413 (2008), which takes 15 to 20 days to develop. Before mounting the test pieces were dried in an oven at 103 ± 2 °C, weighed in a balance of 0.01 g of precision up to constant mass, and intended for the assembly of the tests. The test was mounted in flasks of 600 ml capacity, within them was placed 300 g of soil with pH of 7.62 and water retention capacity of 46.71%, the soil was moistened for 130% holding capacity by adding 47ml of distilled water and then adding two pieces of *Pinus caribaea* wood as feeders for the fungi (figure 2)

Entre Fig. 2

The set of bottles and feeders were sterilized in an autoclave at 103 kPa and 121 °C for 30 minutes. This procedure was followed from the indications of ASTM D-1413 (2017). After the sterilization process fragments of ± 1cm² of the xylophages fungi originating from pure cultures were placed, these were added to the feeding pieces using a laminar flow chamber. After the mushrooms had covered the wood feeder part and part of the soil, two samples of wood plastic composite were placed in each bottle. All fungal handling operations (inoculation, introduction of the samples in the bottles) were carried out under aseptic conditions.

The test was maintained in a heated room (25 ± 2 °C temperature and 65 ± 5% relative humidity) for 12 weeks. After the end of the test the test tubes were cleaned to remove the mycelia from the fungi and placed in an oven at 103 ± 2°C until constant mass was obtained, then they were weighed again. The classification of the strength of the plastic wood board was made according to ASTM D - 2017 (2005).

The initial weight of each of the test pieces was obtained, as well as the dimensional measurements (density, thickness) were taken, these values were used to calculate the loss of mass caused by the fungi. This calculation was determined by the following mathematical equation:

$$PM = \frac{P_f - P_i}{P_i} * 100 \quad [1]$$

were:

PM: loss of mass (g)

P_i: initial weight (g)

P_f: final weight (g)

The classification of the board before the effect of the fungi was carried out according to the requirements of the ASTM D - 2017 standard, as shown in table 1.

Entre Table 1.**Statistical analysis**

The results were processed using the statistical tools according to SPSS version 21. The descriptive analysis was used to characterize the variables, the assumptions of normality were evaluated by the text of Shapiro-Wilk to have a better statistical inference when the assumption of normality was not met ($P < 0.05$). The associated statisticians were analyzed to determine the significant differences between each treatment using the Kruskal-Wallis test.

Results:-

Table 2 shows the results obtained according to the exploratory analysis of the data for a confidence interval of 95% of the means. The values reflected in are for the loss of mass, the swelling in thickness, and the density of the specimens for treatment 1

Entre Table 2

The evaluated fungi caused dimensional alterations in relation to the thickness swelling of the specimens, being higher for *Postia placenta* compared to *Trametes versicolor*, for both treatments. The results obtained show that *Postia placenta* caused a mass loss of 6.41% in Treatment 1.

Even when resistance to fungal attack is within the highly resistant (AR), moisture absorption altered its dimensional stability by 3.75%, these parameters being greater for treatment 2 (Table 3). It is important to consider that the effect of the fungi, regardless of the type of technological processing used for the elaboration of this type of board, can undergo dimensional transformations; xylophage agents cause this.

Entre Table 3

According to the statistical parameters obtained from the loss of mass and thickness swelling, there were no significant differences in the treatments with respect to the fungi evaluated; in addition, the values obtained were low. However, such physical damage can affect the properties of the boards when they are arranged to weather conditions or humid places. This can be the result of a poor interaction between the wooden and plastic interfaces within the compound. This was type of interaction was even more accentuated in treatment 2 in which during the production of the board, the thermoplastic does not completely melt and mix with the wood particles; this creates zones of faults that can allow the entrance of humidity and consequently infection by the fungi. Figure 3 shows the evolution of the fungi in the specimens.

Entre Fig. 3**Discussion:-**

A comparison of the results obtained by different researchers such as Paes et al. (2004); Carrillo et al. (2011), Teixeira et al. (2015) on the action of xylophages agents in solid wood, give important information that allows one to select those woods that offer greater resistance to these agents; this information can also be applied on raw materials, in the manufacture of wood plastic composite; the proportion of wood in these boards can vary and exceed 60% and the researchers conclude that these agents can cause mass loss between 2 and 40%. It is also important to point out possibility of obtaining better results in plastic wood boards, in terms of the effect of these deteriorating agents, than in solid wood.

Studies conducted in composites produced whit glass fiber and jute, was evaluated the effect of the fungus *Trametes versicolor* and *Terebraliopalustris* on the boards, obtained more than 60% of the moisture content of the board after the attack of the fungi, in relation to weight loss obtained more than 40%. weight lost in the composite varied between 1.98 and 4.44% similar result were obtained in this research, there were slightly higher weight losses in specimens containing either glass fiber only or glass fiber plus jute fabrics (Terzi et al., 2018).

The resistance of the wood plastic composite to the attacks of these deteriorating agents on the board occurs because of the lack the enzymes necessary to degrade the lignocellulosic material (wood). The result is board with a high quality and resistant material.

The resistance is also given because the thermoplastic matrix allows the encapsulation of wood particles mainly in treatment 1; this offers the material a greater resistance to water absorption and swelling in thickness; in addition, this decreases the effects associated with decomposition caused by the fungi that attacks the wood. In Figure 4, the

distribution of the raw materials used in the two treatments evaluated in this study can be observed by microscopic image.

Entre Fig. 4

Figure 4, can be observe the result of the compression processing (treatment 2), in which the wood particles do not reach to mix completely with the thermoplastic matrix. This union is favored by the use of glue (phenol formaldehyde) which also presents difficulties to diffuse between the particles. This condition favors the creation of zones of faults, which allow the entry of water to the board and consequent deterioration against xylophages agents. For its part, the processing by extrusion (treatment 1) allows a better interaction of wood particles and thermoplastics, because they get to melt completely given the temperature reached during the technological process. Its compaction is superior in relation to treatment 1, which allows it to obtain a better response against xylophages agents.

Results obtained by Cervantes et al. (2015) in agglomerated boards of coconut trees, had results of mass loss over 3%, despite being a value lower than that obtained in this study, showed a swelling in thickness greater than 46%, and a loss of the density of the board of 36%, all these changes caused by *Postia placenta*. Mendes et al. (2013) in contrast, obtained values of mass loss greater than 8% for oriented fiber boards obtained with *Pinusteada* L. wood, and density of 650 kg.m⁻³. Mendes et al. (2014) reported values greater than 11% of mass loss in plywood panels in relation to the attack of *Trametesversicolor*.

Conversely, Xu et al. (2013) obtained favorable results treating the wood with borate to evaluate the resistance of oriented particleboards (OSB), to the effects of the fungi *Gloeophyllumtrabeum* and *Trametesversicolor*. The results obtained in this study allows one to corroborate both treatments as carbonate of calcium was used as a chemical additive to decrease the permeability of the boards and conditioned better consistency and hardness, given the density reached.

The density of the boards constitutes one of the main indicators of quality and hardness of these materials. In the case of wood plastic composite, its density is influenced by the good encapsulation of the wood particles by the thermoplastic material, as well as its compression ratio, which in this study was 1.75 for treatment 1 and 1, 53 for treatment 2, both are considered as very good (Zabihzadeh, 2010).

Taking into account the results obtained during the test, the evaluated fungi caused a little significant effect in on the density of the board at a loss rate of 20%, for the samples that were under the effects of the fungus *Postia placenta*; *Trametesversicolor* presented a decrease of 23% and the control 8% for Treatment 1. This treatment provided greater resistance, in which case the fungus probably found more difficulty in translocating its enzymes in the more compacted panel.

Other studies carried out by Ashori et al. (2013) the durability of wood flour/high density polyethylene (HDPE) compounds treated with chemical preservatives for the white rot fungus (*Coriolusversicolor*). The experimental results indicated that the treated compounds were more resistant to decomposition, with losses of resistance significantly lower than the untreated sample (control). The physical properties in terms of water absorption and swelling of the thickness were improved by the incorporation of fungicidal agents, but no significant differences were observed between the trampled samples.

The weight loss varied from 1.1% to 4.5%, the values obtained in this investigation were similar, with a better response for *Trametesversicolor* of 3.15 in treatment 1. In this investigation calcium carbonate was used to improve the compaction of the board in each of the treatments evaluated, the physical properties of density and water absorption is shown better in the boards obtained by extrusion (Trtatamiento 1).

The density for treatment 2 was affected in 30% for *Postia Placenta* and 35% for *Trametesversicolor*, and the control in 10%. This difference is mainly due to the processing conditions of each treatment, using temperatures higher than 200 °C which allow the thermoplastic to encapsulate the wood which provides better physical properties in relation to the method used in the Treatment 2.

The xylophages fungi can cause the deterioration and decay of these types of boards, they are considered one of the major causes that affect their durability of wood and wood products, since they use wood and its components as

source of food in conditions conducive to its development (moisture). This is why it is important to provide more resilient and more value-added products for society (Yeh et al., 2009).

Studies conducted by Fenget al. (2014) the resistance to fungi and water absorption of wood plastic composite (WPC), made from wood / HDPE and bamboo / HDPE with different fiber content as a test material. The results show that the resistance to fungi varied with the fiber content. The compounds with higher fiber content were more susceptible to fungi showing clear evidence of fungal growth and colonization in the WPC sample. The water absorption of WPC was jointly affected by the increased content of wood or bamboo, which progressed rapidly, as well as the growth of fungi, was also promoted with the water absorption of WPC. The studies carried out in this investigation were stable since the wood content was the same for the two treatments, this demonstrates the search of adequate formulations that adjust to humidity conditions and improve the resistance to biological agents

Conclusions:-

The wood plastic composite produced under the dosages referred to in this study were classified as highly resistant (Treatment 1) and resistant (Treatment 2) to deterioration caused by the xylophages fungi *Postia placenta* (brown rot) and *Trametesversicolor* (white rot).

Even though the evaluated treatments did not show statistical differences, it was demonstrated that *Postia placenta* has a greater influence on the physical properties evaluated in the panel in relation to *Trametesversicolor* for both treatments.

It was demonstrated that plastic wood composite manufactured by extrusion molding (Treatment 1) have better properties and strength before these xylophagous agents than the boards produced by compression (Treatment 2). This difference is given by the better encapsulation of wood particles by the thermoplastic matrix in the production process, and provided greater resistance, in which case the fungus probably found more difficulty in translocating its enzymes in the more compacted panel.

The obtained results allow to evaluate the effect of said xylophages fungi in this type of board, this contributes to create a starting point to elaborate more resistant boards from modifications in the contents of raw material, with better perspectives from the increase of the proportions of thermoplastic to decrease water absorption of the board and thus the impact of deteriorating fungi.

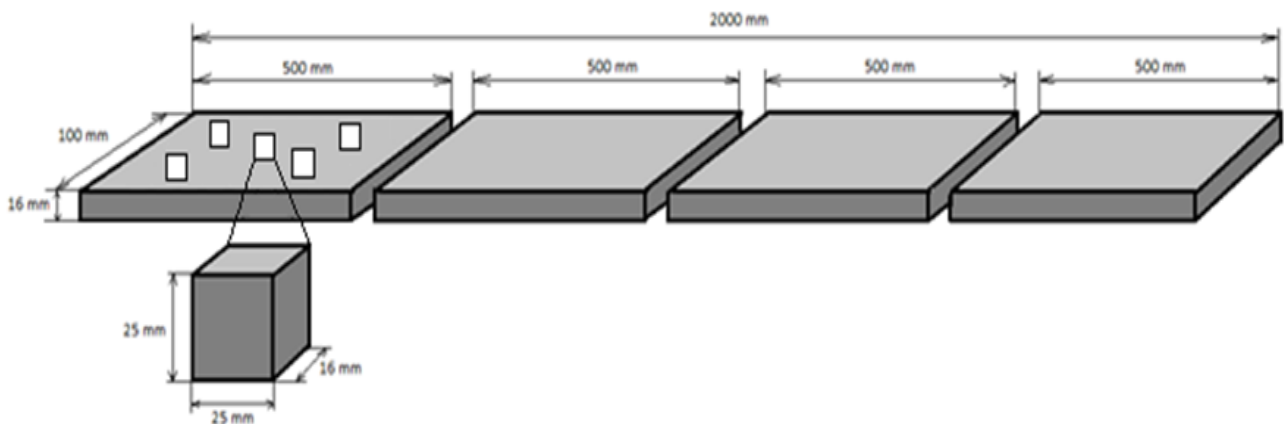


Figure 1:-Methodological design of extraction of the samples



Figure 2:-Methodological design of the assembly for the test.

Table 1:-Classes of resistance to the attack of xylophages fungi.

Loss of Mass (%)	Residual Mass (%)	Resistance Class
0 - 10	90 - 100	Highly Resistant (HR)
11 - 24	76 - 89	Resistant (R)
25 - 44	56 - 75	Moderately Resistant (MR)
≥ 45	≤ 55	Not Resistant (NR)

Source: adapted from the ASTM D - 2017 (2005).

Table 2:-Statistical parameters evaluated for the trial of treatment 1

Parameters	Fungis	Kruskal-Wallis	Median (%)	Variance		
		Estatistical	df	Sig.		
Loss of mass	<i>Postia placenta</i>	0,217	20	0,200 ^{ns}	6,41 HR	0,81
	<i>Trametes versicolor</i>	0,268	20	0,200 ^{ns}	4,15 HR	0,58
	Testigo	0,222	5	0,000	1,76 HR	0,12
Thickness swelling (%)	<i>Postia placenta</i>	0,200	20	0,200 ^{ns}	3,75	2,77
	<i>Trametes versicolor</i>	0,273	20	0,200 ^{ns}	2,83	1,31
	Controle	0,242	5	0,000	0,49	0,55
Density (kg.m ⁻³)	<i>Postia placenta</i>	0,250	20	0,148 ^{ns}	818,4	4.039,1
	<i>Trametes versicolor</i>	0,280	20	0,200 ^{ns}	871,1	1.539,8
	Controle	0,275	5	0,000	943,9	2.670,8

HR: Highly Resistant. R: Resistant. ns: They do not have significant differences.

Table 3:-Statistical parameters evaluated for the trial of treatment 2

Parameters	Fungis	Kruskal-Wallis	Median (%)	Variance		
		Estatistical	df	Sig.		
Loss of mass	<i>Postia placenta</i>	0,322	20	0,200 ^{ns}	12,01 R	0,91
	<i>Trametes</i>	0,341	20	0,200 ^{ns}	10,04 R	0,73

	<i>versicolor</i>					
	Controle	0,353	5	0,000	4,42 HR	0,32
Thicknessswelling (%)	<i>Postia placenta</i>	0,365	20	0,150 ^{ns}	5,42	3,84
	<i>Trametes versicolor</i>	0,301	20	0,200 ^{ns}	4,61	2,51
	Controle	0,321	5	0,000	1,41	0,85
Density (kg.m ⁻³)	<i>Postia placenta</i>	0,379	20	0,200 ^{ns}	644,3	5.072,1
	<i>Trametes versicolor</i>	0,384	20	0,178 ^{ns}	598,2	1.629,8
	Controle	0,364	5	0,000	828,3	2.970,8

HR: Highly Resistant. R: Resistant. ns: They do not have significant differences.

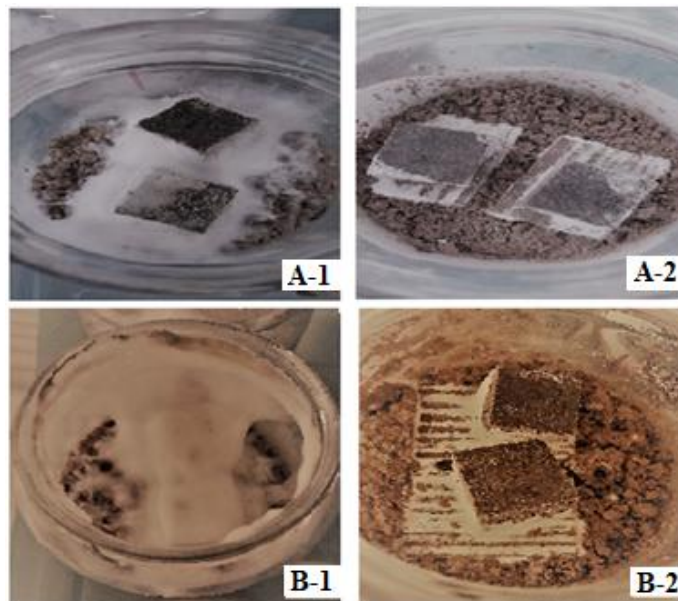


Figure 3:-Effect of fungi on plastic wood specimens. A-1): *Postia placenta* in treatment 1, A-2): *Trametesversicolor* in treatment 1; B-1): *Postia placenta* in treatment 2, B-2): *Trametesversicolor* in treatment 2

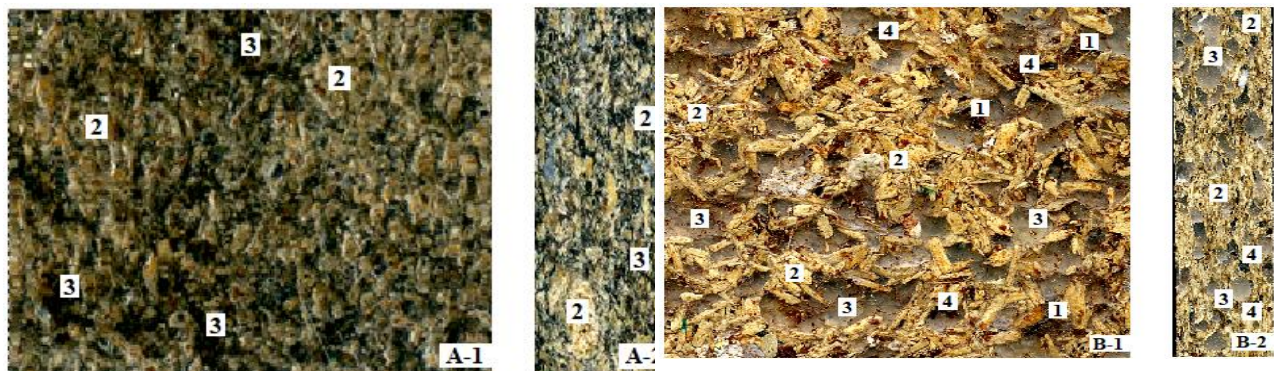


Figure 4:-Microscopic structure of the wood plastic composite. A-1 Front view of wood plastic composite (treatment 1); A-2 Side cut of wood plastic composite (treatment 1); B-1: Front view of wood plastic composite (treatment 2); B-2 Side cut of wood plastic composite (treatment 2) 1:Drops of adhesive; 2- wood particles; 3- molten plastic; 4- fault zones

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