749

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Coated Particleboards based on Castor Stalk Waste as an Alternative to Artificial Wood: (Part II)

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Abstract

The coating of the particleboard often challenges researchers in the wood industry, and only a small portion of the literature focuses on particleboard coating, practically and academically. This study focuses on the properties of pigmented coatings that mix acrylic-styrene latex with alkyd latex on the particleboards made from castor stalk. By testing abrasion resistance, UV resistance, hardness, adhesion, pull-off test, water, and chemical resistance, the performance of the blends in pigmented coatings was assessed. The performance of the surface qualities of coated caster particleboard was improved due to pigmented coatings. Coating, moreover, significantly enhances gloss and abrasion resistance further.

Keywords; Castor Waste, Particleboards, Surface Coating, Surface Properties, Mechanical Properties.

Introduction

Currently, wood chip panels are widely used in many different human efforts, especially in the construction and furniture industries. The most popular panels are particleboards, which are made from wood chips. In particleboard, a type of wood-based composite, fine wood fibers are joined together using a small amount of polymeric adhesive, which is a crucial component of the composites market [1]. The expansions of applications that have a significant impact on the resources of standing forests and the rise in global population have both increased the demand for the production of wood composites. In contrast, the supply of wood for particleboard production has decreased due to natural forest deforestation [2]. The rising global demand for forest products drives the quest for new raw materials and the most effective use of existing raw resources. Agricultural leftovers are a great alternative source that can be utilized in place of wood and wood fibers if performance is satisfactory because they are plentiful and renewable year after year [3, 4]. Substitution seems inevitable given the increased consumption of raw woody materials. To balance supply, it will be crucial to use alternative raw materials such as under-utilized species, quickly expanding species, crops, and other plant fibers [5, 6]. Biomaterials are preferable to synthetic equivalents in terms of cost, toughness, density, superior specific strength properties, processability, and biodegradability [7]. Particleboard production has successfully used various agricultural waste products, including wheat straw, sugarcane, sunflower seed hulls, castor stalks, bamboo, and palm. These products are currently offered on the market under several trade names [8]. Castor stalks are one of the neglected bio-based resources that could give the particleboard industry a non-food market. Castor stalks, commonly known as castor oil plant or Ricinus communis Linn, are a species of perennial flowering plant belonging to the spurge family, Euphorbiaceae [9, 10]. The plant is indigenous to Ethiopia in tropical Africa, but it has spread to temperate and tropical areas worldwide [11]. The plant is a durable annual that may reach heights of 2 to 5 meters, but because it is moisture sensitive, it performs best when planted during the rainy season [12].

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Particleboard is a material that is produced in huge quantities and is mostly used to make furniture since it has strong mechanical qualities and is easy to work with [13, 14]. It is the most widely used panel material for non-structural uses. Because it is flexible and less expensive than other types of wood-based panel materials, particleboard is very popular [15, 16]. A raw board with several applications is particleboard. It is a partially completed item. Today, it is customary for particleboard to have a specific coating before being utilized in final products in the furniture industry and for interior design. In addition, particleboard coating covers the board's surface with materials that are more aesthetically pleasing and more resistant to external forces than the board itself [17, 18]. When particleboards are coated with different coating materials, their basic mechanical properties (modulus of elasticity E and modulus of rubture) alter [19]. A higher-quality and more expensive final product is produced due to particleboard coating, which improves the board's surface quality, or namental qualities, age resistance, and formaldehyde emission. Several methods are used to coat particleboard surfaces for outdoor use. Various materials, including impregnated papers, paint, varnish, prints, laminates, foils, and others, are currently used to create products produced from particleboard panels [20]. In the furniture industry, particleboard is frequently coated with veneers, and polyvinyl chloride (PVC) foils.

Today, the fabrication of flooring, wall cladding, and office furniture is predominantly done with particleboards. Large organizations' boards may be impacted by various circumstances, which may also impact the organization's entire structure. However, particleboards must be protected from various biotic and abiotic elements for their use to last longer. Different forms of protection have so far been created, and new technologies are still being created in this field. Coating, which includes all varieties of paints, varnishes, stains, lacquers, etc., is one way to protect particleboard [21, 22]. When particleboard surfaces are directly finished (coated or painted), increasing attention must be paid to surface quality. A good surface quality makes coating materials easier to apply and lowers finishing procedures' costs [23]. Water-borne, solvent-borne, UV curing, and other technologies are relevant to coating wood. The effectiveness of exterior and interior wood treatments depends on their capacity to cover and adhere to wood surfaces. For various intended uses, it is also necessary to conduct extensive research on the interactions between the coating, the wood substrate, and external influences. The wood substrate affects a coating system's performance. Wood plastic composites (WPCs) surface quality level depends on the raw materials' properties and the manufacturing processes [24].

Consequently, this work focuses on coating particleboard made from castor stalks as agriculture waste. A mixture of acrylic-styrene latex and alkyd latex was used during the coating process. Mechanical Properties, scratch hardness, the ability of a film to resist removal from a substrate, chemical resistance, UV resistance, and abrasion resistance were measured to study the effect of coating pigment on the properties of produced particleboards.

Materials and Methods

Materials

The castor stalks (*Ricinus communis* L.) used in this study were harvested in December 2020 from New Valley Governorate, Egypt, where the plant normally grows to about 3 to 5 m in height. It measures between 10 - 50 mm in diameter with a hollow core. Castor stalks of this variety were oven-dried and stored in sealed plastic bags at 20 to 28 ˚C and relative humidity of 40 - 60%. Three sampling areas were defined on one stem, the lower part was between 0 - 10 cm (the fiber bundle diameter was between 10 - 12 mm), the upper part was between 60 - 70 cm (the fiber bundle diameter was between 6 - 8 mm), and the branch parts were between 90 - 100 cm (the fiber bundle diameter was between 3 - 6 mm). The main chemical constituents of the castor stalk are cellulose, hemicellulose, lignin, ash, and extractives with 50.46, 29.64, 17.34, 1.48, and 3.12 %, respectively.

Coating ingredients

Titanium dioxide (TiO_2) crystal 128, was purchased from crystal Company, Saudi Arabia kingdom. Soybean oil alkyd resin 62.5 % was purchased from Eagle company, Egypt. TRITEX SA 50 Sytrene Acrylic Copolymer. Solid Content, 50,0 (±2), %. Viscosity, 1000 – 3000, cps. MFFT, 18 (±2), °C ,it was provided by Trison Polymers. Dispersing agent; (Hydropalat 5050) was imported from Cognis , UK. (Foam master NDW); was imported from Cognis, UK .Ca naphthenate, Co naphthenate, and Zr naphthenate were purchased from Chemical Partner Company, 10^{th} of Ramadan City, Egypt. Biocide (Rocima 623); was obtained from Chemical Partner Company, 10^{th} of Ramadan City, Egypt. ACRYSOL™ RM-8W Rheology Modifier hydrophobically-modified ethylene oxide urethane (HEUR) rheology modifier it was provided by Dow company. White Spirit is a solvent it was provided by local company.

Characterization of coating solution

Viscosity Measurement

The viscosity of the prepared coating formula was measured according to ASTM [25] using a digital Brookfield viscometer. The viscosity was calculated as the average of three experimental determinations.

Determination of Solid Content

The solid content of the prepared polymers was determined according to ASTM D [26] by weighing an adequate amount of the sample in a petri dish and heating it in an aerated oven at 105°C till a constant weight was obtained. The solid content was calculated as the average of three experimental determinations.

$$\text{Solid content (\%)} = W_f/W_i \, X \, 100$$

Where W_f and W_i are the drying and the initial weight of the sample, respectively.

Stability Test

Place 200 gm of a sample in a impenetrable can and subject the can to a temperature of 50°C for one month. After one month, visually check if any water has phase separated out of the formulation and if any settlement has occurred. After mixing the coating formulation homogenously, manually apply the coating formulation with 250-micron wet film thickness on a steel Q-panel. Then test the film performance of the resulting film coating.

Coated Particleboard Preparation

The first particleboards of dimensions, 200 X 200 X 5 mm were prepared. The total ratio of solid polymer adhesive % by weight based on castor raw material is shown in **Table 1.** Hot pressing was carried out at 100 kg/cm^2 pressure and 180 °C, for 10 minutes' press time. Particles were dried to approximately 3 % moisture content prior to the application of resin. The particleboard density was 657 kg/m^3 which could be considered an MDF.

Coating film application

The coating formula used in this work consisting of pigment, binders and other additives as shown in **Table 2.** The solid content, viscosity, pH, and fines of the prepared coating formula were 60.2 %, 30000 Cp, and fines 30 Hegman gauge (grind gauge), respectively. The pH was adjusted to 8-8.5 using 1M triethanolamine.

The coated samples were applied to particleboards obtained from the caster tree by using the spray gun and brush to obtain an appropriate and uniform dry film thickness (**Figure 1**). The coating process is done in three layers as follows:

The first layer from the prepared formula was diluted to 50 % with white spirit applied using the spray gun. After complete drying second coat layer from the prepared formula was diluted to 20 % with white spirit and applied using a brush, and after complete drying third coat layer from the prepared formula was diluted to 10 % with white spirit and applied using a brush.

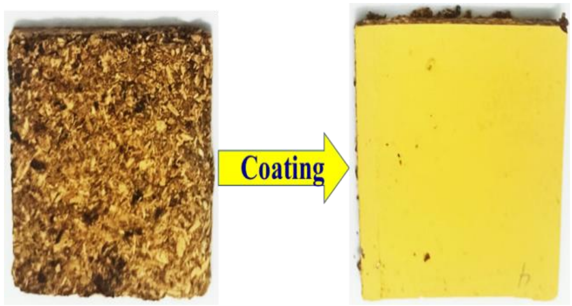

Figure 1. The uncoated and coted particleboards made from castor stalks.

Characterization of the coated particleboards

Specimens for Testing

After coating , boards were conditioned at 20°C and 65% relative humidity for 72 h and then trimmed and cut into specimens of specific dimensions suitable to various tests. The specimens were conditioned again at a temperature of 20°C and 65% relative humidity for 72 h. Testing of specimens was carried out according to EN standards. Two replicates were tested for each property under each formulation. Thickness was measured using a dial micrometer.

Table 1. Binder ratio used in particle board preparation.

Code No.	Binder	%
CS1	Styrene Acrylic (Soft)	15
CS2	Styrene Acrylic (Hard)	15
CS3	Polyvinyl Acetate	15
CS4	Styrene Acrylic (Elastic polymer)	15
CS5	Siloxane Resin	15
CS6	Styrene Acrylic (Elastic polymer)/ Siloxane Resin	7.5/ 7.5
CS7	Siloxane Resin/ Styrene Acrylic (Hard)	7.5/ 7.5
CS8	Siloxane Resin/ Styrene Acrylic (Soft)	7.5/ 7.5

Table 2. The ratio of coating formula.

Component	Function	Weight %
62.5% Alkyd soybean oil	Binder	49.2
Hydropalat 5050	Dispersing agent	0.8
Foam master	Defoaming agent	0.3
2% Ca naphthenate	Catalyst	0.65
4% Co naphthenate	Catalyst	0.2
10% Zr naphthenate	Catalyst	0.7
Acrysol rm 8w	Thickener	0.9
TiO_2 crystal 128	Pigment	24
White spirit	Solvent	8.3
TRITEX SA50	Co-binder	8
Deionized water	Solvent	3
Rocima	Biocide	1
Total		**100**

Mechanical Properties

For mechanical properties, modulus of rupture (MOR) and modulus of elasticity (MOE) were measured according to EN 310[27]and according to EN 319[28]. by using the LLOYD INSTRUMENTS LR 10K universal testing machine. The five specimens from each sample were tested, and the results were averaged.

Hardness measurement

The scratch hardness of the coated samples dry films was evaluated by a pencil hardness test. The test procedure was done using the Sheen Pencil Hardness Kit accompanied by a set of calibrated wood pencils with a scale of hardness 6B (softest) to 6H (hardest). The hardness was expressed in terms of the designation of the hardest pencil that failed to scratch the film.

Adhesion measurement

The ability of a film to resist removal from a substrate is certainly an important coating property. The adhesion of the coating to the wood substrate was evaluated using a cross-cut test method. The cross-cut test instrument used in this was manufactured by Sheen Company with a cross across-hatch.

Gloss

Gloss describes the mirror-like property of a coated surface and is defined as the percentage of the light that is reflected from the surface at an angle equal to the angle of incidence, in comparison with a standard surface. Gloss was measured by a micro gloss meter, at an angle of 60°.

Chemical resistance

The chemical resistance was tested for the 24h and 72h cures. The chemicals used in the test were vinegar 5%, methanol 85%, lemon juice 100%, and a cleaning solution 5%.

Pull-off test

The adhesion of a coating is measured by assessing the minimum tensile stress needed to detach or rupture the coating perpendicular to the substrate. Unlike the other methods, this method maximizes the tensile stress, therefore results may not be comparable to the others. The test is done by securing loading fixtures (dollies) perpendicular to the surface of a coating with an adhesive. Then the testing apparatus is attached to the loading fixture and is then aligned to apply tension perpendicular to the test surface. The force that is applied gradually increases and is monitored until a plug of coating is detached, or a previously specified value is reached. The pull-off test was done by a posi tester according to the ASTM Standard for Pull-Off Test [29].

UV Exposure

UV resistance of the coated samples was tested using stander UV chamber at 340 nm. Exposure time: (300 h exposure-12.5 days in total) - Rating of defects due to ageing in accordance with ISO 4628-6,7.

Ultraviolet exposure (UV testing) is performed to understand how a material will withstand the damaging effects of ultraviolet exposure, which can cause significant changes to the properties and useful life of a material. Prolonged exposure to UV rays can cause a host of issues, including fatigue and reduction of strength, yellowing or discoloration, cracking, brittleness, and general deterioration. To combat this, UV testing simulates the sun's ultraviolet rays in a controlled laboratory setting.

Resistance to abrasion

The abrasion resistance tests were done according to the Taber Abraser method (EN 438-2) [30] on 10 samples per series. After weighing, the specimens were mounted into the rotary platform abrasion tester (Taber abrasion –USA) and abraded with rotating rubber wheels covered with sanding paper S-42 and loaded with 500 g each. The abrasion process was stopped after 10, 25, 50, 75, 100, 150, and 200 revolutions. After each stop, the samples were weighted. A fresh sanding paper was used with every sample. A mass loss of the sample was determined according to the following equation:

$$\Delta m\ \% = (m_0 - m_1)/ m_0 \ X\ 100$$

Where Δm is the sample mass loss due to abrasion (g, %), m_0 and m_1 are the sample's mass (g), before and after abrasion, respectively.

Results and Discussion

The stability and fineness test

The stability and fineness test results of the coating color formula after one month of storage at 50 °C showed no water out, no settlement, and the film appearance was good (smooth and glossy). Also, wet paint fineness by slight change after storage at 50°C for one month from 30 to 33 which can be neglected and has no effect on coating performance.

Mechanical Properties of Coated Caster Particleboards

Table 3. The mechanical properties of coated castor particleboards.

Code No.	Maximum Bending Stress at Maximum Load (MPa)	Elastic Strength (MPa)	Young's Modulus of Bending (MPa)
CS1	4.5438	3.284	1978.65
CS2	8.0024	6.022	29858.9
CS3	3.2749	1.150	4772.22
CS4	2.5226	2.150	12439.5
CS5	1.1489	0.712	44310.8
CS6	6.0441	0.513	1501.45
CS7	2.4535	0.520	8628.45
CS8	3.1881	2.651	1370.6

Modulus of Rupture (MOR)

The coating of particle board was aimed to increase the surface properties like gloss, surface adhesion, hardness, and abrasion resistance.

The coating layer thickness is 180 microns, and the thickness of prepared particle boards are 3000 microns, so the mechanical properties for the whole sample (coat layer 180 microns + base particle board 3000 micron) is due to the resin used in forming stage and slightly affected by coat layer. The results (**Table 3**) showed that coated boards made with hard and soft styrene acrylic, elastomeric and siloxane blend, and PVA, revealed higher mechanical properties compared to that made with siloxane resin, elastomeric resin, and a mix of siloxane with soft, and elastomeric resin this is due to Tg of resin and thermal performance during pressing in making stage. The maximum values of the MOR were 8.0024 and 6.0441 for hard styrene acrylic resin sample CS2 and elastomeric /siloxane blend sample CS6, respectively. The properties of particleboards can vary depending on the resin type. This may attribute to the complex nature of caster wood raw materials. Therefore, the properties of the caster particle board are largely determined by the characteristics of the resin. The mechanical properties improved with the addition of hard and soft styrene acrylic, elastomeric and siloxane blend, and PVA however, sample CS2 has the highest value of MOR. These results show that filling the voids between the particles with hard styrene acrylic; improves the compaction of the particle board, leading to the improvement of the mechanical and physical properties.

Elastic Strength

As shown in **Table 3,** the elastic strength of coated caster particle board made with hard and soft acrylic resin showed a higher internal bond than those made with elastomeric, siloxane, and a mix of siloxane with hard/soft and elastomeric resin. The higher internal bond values range from 6.022 to 3.28 for hard and styrene acrylic. This results due to the high compaction of caster particle board and correctness of resin caused faster heat transfer to the core layer resulting in more curing of resin [31].

Young's Modulus

Young's modulus (44310.8 MPa) while using hard styrene acrylic gives 29858 MPa. The high values are attributed to the higher flexibility of styrene acrylic resin. This could be accounted for by higher internal structure and higher adhesive solidification. From the above data, it was observed that the type of adhesive had an important effect on the particle board's mechanical properties.

In this range, the board's strength increases because of the variability of the properties of polymeric substances, which are involved in their composition.

The composition of the caster particleboard is very complex, but cellulose and lignin constitute the basic parts [32]. According to the results, the composite SC5 and SC2 show a higher modulus of rupture. Castor particle boards were successfully moulded and coated, and their characteristics are promising for commercial use.

Physical and chemical properties of coated caster particleboards

Coated caster particleboard shows a firm, constant coat weight and dry film thickness for all samples. This is related to good surface preparation before the coat and coating layer are applied in the same manner for all samples. Coated caster particle board shows excellent water and UV resistance. No film defects such as chalking, pitting, gloss reduction, etc., were seen, which are one of the most significant features in particleboard application. This finding complies with [33, 34]. The adhesive coating protected the surface against degradation in sunlight.

Table 4. Physical and chemical properties of coated caster particleboards.

Code No.	Thickness micron	Coat weight G/m2	Gloss	Adhesion by cross cut	Hardness	Pull off	UV resistance	Water resistance
CS1	180	100	29.5	4B	4H	10.200	Pass	Pass
CS2	182	104	29.8	4B	5H	17.350	Pass	Pass
CS3	180	100	29.2	4B	4H	10.350	Pass	Pass
CS4	181	100	29	5B	2H	8.350	Pass	Pass
CS5	180	100	29	2B	2H	8.350	Pass	Pass
CS6	181	102	28.2	5B	5H	15.350	Pass	Pass
CS7	180	100	30.2	4B	3H	8.350	Pass	Pass
CS8	180	100	33	4B	5H	11.200	Pass	Pass

Coating a wood product can improve color stability and avoid dramatic changes to the surface appearance during service life. The water resistance of coated caster particleboard results from the formation of covalent bonds between hydroxyl groups in the wood waste and the polymer. These bonds help to connect the polymer in the particle board to the wood waste, thereby bridging the gap between the wood waste particles. This adhesive network also helps to create polymerized linkages with molecules in the wood waste, which is an important contributor to the water resistance properties of particle boards [35, 36].

According to Vikas et al. [37], using a polyurethane film based on palmitic acid to coat a panel provided increased water resistance with increasing NCO index due to increased crosslink density and hydrophobic character of the polyurethane film [38].

Gloss values, as shown in **Table 4**, were measured at three points for each sample. Gloss values show an acceptable range (28.2 - 33) attributed to the coated samples' uniform and smooth surface.

Adhesion

Table 4 shows the results of the coating adhesion test for the coated samples that were tested. The adhesion test is the most important attribute of a wood coating. The coated sample (CS6 and CS4) had excellent adhesion 5B and performed better at dry crosshatch adhesion than the other coated sample. The rest samples also have the same value, 4B, which is good for the surface of the coated board. Sample CS4 showed low adhesion values 2B. This is binder behavior used in the making stage. Sample CS4 is made using elastomeric styrene acrylic, which gives a nonporous surface after coating. The coating layer shows corrupt adhesion.

Hardness and Pull off Test

Pencil hardness and pull-off results for all coated samples were tested, and the results are shown in **Table 4.** This test is used to predict the toughness and scratch resistance of the coating. Coated samples no. (CS2, CS6, and CS8) showed best results for hardness. Pull-off results match hardness results; coated samples no (CS2, CS6, and CS8) showed the best values of pull-off results.

Abrasion Test

Table 5 representative samples taken during the abrasion test after a certain number of revolutions. The differences in the amount of abraded coating were shown already after the 200 revolutions.

After 100 revolutions, the differences reached the maximum (about6- 10 % mass loss), and the max mass loss in the coating layer reached 100% after 200 revolutions. The complete removal of the coating layer after 200 revolutions complies with that obtained by Žigon et. al. [39].

The reason for that could be a greater hardness of the coating film and/or deeper penetration of the coating, however, due to the compressed structure of the cells. The results showed that on the samples coated with the above formula, it could be concluded that increased abrasion resistance of the coated sample is related to the greater hardness of the coating film applied on such a substrate.

Chemical resistance of surface

The chemical resistance test data for the 24 h and 72 h treatments are shown in **Table 6.** The chemicals tested were vinegar, methanol, lemon juice, and a cleaning solution. The all-coated sample showed excellent chemical resistance to the 24 h cure. After 30 min emersion in a chemical solution, the coating did recover to its original color. The color of the samples did not fade with time, but for 72 h cure, the coated sample showed moderate and very slight color fading, which recovered to its original color after one day of drying. This proves the suitability of our coating formula for that type of caster particle board and the coated samples' good binding, film formation, and surface smoothness.

Table 5. Absolute mass loss % of coating layer during abrasion resistance test relative mass of the whole sample.

Code No.	Number of revolutions						
	10	25	50	75	100	150	200
CS1	0.20	1.0	2.0	3.3	6.2	38	100
CS2	0.22	0.8	2.0	3.2	6.0	35	100
CS3	0.23	1.2	2.8	3.6	6.5	35	100
CS4	0.30	0.9	3.0	3.5	6.2	45	100
CS5	0.22	1.2	2.0	3,8	6.9	44	100
CS6	0.28	0.9	2.2	3.5	7.0	47	100
CS7	0.30	1.0	2.0	3.7	7.0	35	100
CS8	0.29	1.0	2.0	3.3	10.0	40	100

Table 6. Chemical Resistance of Coated Surface of Caster Particleboards.

Code No.	Chemical resistance							
	24 h				72h			
	Vinegar 5%	Methanol 85%	Lemon juice 100%	Cleaning solution 5%	Vinegar 5%	Methanol 85%	Lemon juice 100%	Cleaning solution 5%
CS1	No effect	No effect	No effect	No effect	Moderate	No effect	Very slight	Very slight
CS2	No effect	No effect	No effect	No effect	Moderate	No effect	Moderate	Moderate
CS3	No effect	No effect	No effect	No effect	Very slight	No effect	Moderate	Very slight
CS4	No effect	No effect	No effect	No effect	No effect	Very slight	Moderate	Moderate
CS5	No effect	No effect	No effect	No effect	Very slight	No effect	Moderate	Very slight
CS6	No effect	No effect	No effect	No effect	Very slight	Very slight	Very slight	Moderate
CS7	No effect	No effect	No effect	No effect	Very slight	Very slight	Very slight	Very slight
CS8	No effect	No effect	No effect	No effect	Very slight	Very slight	Very slight	Very slight

Conclusion

Coated particleboards based on castor stalks were successfully prepared by using a mixture of acrylic-styrene and alkyd latex.

- The results appeared that the coating process significantly affected the surface properties, and the mechanical and physical properties of the prepared coated particleboards produced good values.
- The surface abrasion resistance of the coated samples improved with coating.
- The surface hardness and adhesion, and pull-off increased with the coating process.
- In addition, the abrasion resistance of the coated surface shows excellent values even at revolutions greater than 100.
- The coated samples showed excellent chemical, UV, and water resistance.
- The coating layer improves the smoothness of the caster particleboard.
- It possesses good coating properties such as gloss and pencil hardness.

It can be concluded that the coated castor particleboards with acrylic-styrene latex and alkyd latex have qualities that make them suitable for industrial applications.

Conflicts of interest

There are no conflicts to declare.

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