Journal of Oil Palm Research Vol. 32 (1) March 2020 p. 83-89
DOI: https://doi.org/10.21894/jopr.2020.0009

ALTERATION IN COLOUR AND FUNGAL RESISTANCE OF THERMALLY TREATED OIL PALM TRUNK AND RUBBERWOOD PARTICLEBOARD USING PALM OIL

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ABSTRACT

Urea formaldehyde-bonded particleboard made from oil palm trunk (OPT) and rubberwood (RW) were soaked in palm oil for 24 hr before thermally treated in oven at 180°C, 200°C and 220°C. Colour changes and decay resistance against white rot fungus (Pycnoporus sanguineus) *of the samples after thermal treatment were investigated. After thermal treatment, Lightness (L*) of the samples decreased and the extent of darkening increased along with increasing treatment temperature. Generally, RW samples became redder after heat treatment while OPT samples basically showed the same pattern except it became greener when treated at 220°C. Yellowing (positive b* value) was observed at milder temperature and succeeded by bluing at higher temperature. Improvement in fungal resistance was observed for both OPT and RW samples. The weight loss of the untreated OPT and RW samples were 12.97 ± 1.62% and 30.71 ± 1.75%, respectively. At 220°C, the respective weight loss of OPT and RW samples were 4.58 ± 0.44% and 5.78 ± 1.23%. RW showed lower fungal resistance compared to that of the OPT. Strong correlations ($R^2 > 0.75$) were found between weight loss and ΔE* suggested that fungal resistance increased along with increasing ΔE* values.*

Keywords: CIE L*a*b* system, biological durability, thermal treatment, weight loss, wood composites.

Date received: 20 December 2018**; Sent for revision:** 17 March 2019**; Accepted:** 19 June 2019.

INTRODUCTION

Particleboard is one of the reconstituted panels mainly used for interior applications due to the fact that conventional particleboards are bonded with low moisture resistance urea formaldehyde resin (UF). Superior water and fungal resistance are not important for particleboards used in dry inner environment. Nevertheless, these particleboards in use should acquire some ability to withstand some occasional occurrence of wetting as it would facilitate the attack of fungus. A study by Chung *et al.* (1999) revealed that wood composites such as plywood, particleboard, medium density fibreboard and oriented strand board are prone to be attacked by wood-decaying fungi. White rot fungi are often reported to have caused higher weight loss to the samples as white rot consume both carbohydrates and lignin in the wood cell wall compared to the brown rot fungi that only consume carbohydrates. De Melo *et al.* (2015) reported in their study that the weight loss caused by white rot fungi on particleboard made from both rubberwood (RW) and bamboo are higher than weight loss by brown rot fungi.

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A number of treatments have been conducted in improving the biological resistance of particleboard. For instance, Reinprecht *et al.* (2018) incorporated nano-zinc oxide into melamine UF resin and the particleboard made from it exhibited a weight loss reduction of around 86% by brown-rot fungus, *Coniophora puteana*. Despite its effectiveness, application of nanomaterials is still a major concern as it may pose serious threats to human and environment. In contrast, thermal treatment, a green treatment method without application of toxic chemicals, is an effective method to improve the dimensional stability and biological durability of wood and its composites (Boonstra *et al*., 2007). Hakkou *et al.* (2006) recorded a significant improvement of thermally-treated beech wood in resistance against *Coriolus versicolor* and attributed the improvement to the hydrophobic nature, production of toxic compounds and degradation of hemicellulose of wood during heat treatment. *Eucalyptus grandis* wood heat treated at 180°C – 220°C recorded a weight loss reduction of 16%-82% against *Pycnoporus sanguineus* (Calonego *et al*., 2010).

Thermal treatment involving oil has been reported to offer several advantages to the treated wood such as exclusion of oxygen during treatment process and more even and rapid transfer of heat into the wood samples (Lee *et al*., 2018a). Alder wood treated in soya oil at 180ºC and 200ºC for 6 hr and 10 hr exhibited superior resistance against *Postia placenta* (Lacic *et al*., 2014). RW thermally treated in palm oil had enhanced fungal resistance due to changes in chemical constituents (Umar *et al*., 2016). Apart from that, oil heat treatment is also known to cause changes in colour of the treated wood samples. Colour of the treated samples becomes darker and more uniform. The changes in colour were reported to have strong correlation with fungal resistance (Dubey *et al*., 2012). As the darkening of wood are mainly caused by the production of coloured degradation products from hemicelluloses as well as extractives components, it can potentially be used as a good prediction tool for decay resistance of heat-treated wood (Candelier *et al*., 2016).

According to a review done by Lee *et al.* (2018a), there are basically three types of oil heat treatment, namely, oil heat treatment (OHT) by Company Menz Holz in Germany, bi-oleothermal process by France's CIRAD, and Royal treatment. All treatment methods involve the immersion of wood samples into vegetable oils to ensure rapid and even heat transfer into the core of the samples. In addition, the treated wood exhibited better strength owing to the weight percent gain resulted by oil uptake during the process. Study by Lee *et al.* (2018b,c) slightly differed from the above mentioned treatment methods where the samples were soaked into the palm oil prior to heat treatment. The chemical properties, dimensional stability and termite's resistance of oil palm trunk (OPT) and RW particleboard thermally treated with palm oil has been reported by Lee *et al.* (2018b,c). However, the effects of the thermal treatment on the colour changes and resistance against fungus have yet to be reported. This article reports the changes in colour and fungal resistance of the thermally treated particleboards made from OPT and RW. The feasibility of the heat-induced colour changes to serve as a prediction tool for the extent of decay resistance was also investigated.

MATERIALS AND METHODS

Thermal Treatment of Particleboard

RW and OPT particleboards bonded with 8% UF resin as specified in Lee *et al.* (2017) were used in this study. Vesawit edible palm oil (Yee Lee Edible Oils Sdn Bhd, Ipoh, Perak, Malaysia) was used to soak the particleboard samples before heat treatment in the laboratory oven. Before soaking in palm oil, the samples with dimensions of 50 mm long x 50 mm wide x 12 mm thick were oven-dried in a laboratory oven set at 103°C for 24 hr. The oven-dried samples were soaked in palm oil for 24 hr. After 24 hr, the samples were taken out and heat treated in oven at 180°C, 200°C and 220°C for 2 hr. Heat treatment is typically conducted at the temperature levels ranging from 180°C and 260°C, where lower temperatures only altered the material's properties insignificantly while higher temperatures would lead to undesirable degradation to the wood substrate (Lee *et al*., 2018a). Therefore, three treatment temperature levels, namely 180°C, 200°C and 220°C were chosen for this study. After the thermal treatment, the samples were conditioned in a conditioning room until constant mass was attained.

Colour Measurement

Colour of the treated and untreated particleboard samples were measured using Brightness & Colour Meter (Model No. 68-50-00-0001, Messmer Instruments Ltd) through CIE L*a*b* system. The values were obtained from three points of the samples surface. The L* axis represents Lightness where 0 represents black and 100 represents white. The a* axis is green (represented by -a) and red (+a) while the b* axis is blue (-b) and yellow (+b). Colour variations induced by thermal treatment are expressed as the overall colour difference (ΔE*), are determined from Equation (1):

$$\Delta E^* = [\Delta L^{*\,2} + \Delta a^{*\,2} + \Delta b^{*\,2}]^{1/2} \quad (1)$$

Fungal Decay Test

White rot fungus, *Pycnoporus sanguineus*, was used in the fungal decay test for both OPT and RW samples. The test blocks preparation procedures were conducted in accordance with ASTM D 2017-05: Standard Test Method of Accelerated Laboratory Test of Natural Decay Resistance of Woods. The *P. sanguineus* was collected from an infested pine stand from a pine plantation located in the Institute of Bioscience, Universiti Putra Malaysia, Serdang, Selangor, Malaysia. The collected fungi were then cultured in the Wood Deterioration and Treatment Laboratory at the Faculty of Forestry, Universiti Putra Malaysia. Five test blocks had a dimensions of 25 mm long x 25 mm wide x 12 mm thick were prepared for each treatment variable. A total of 40 samples were tested (2 species x 4 temperature levels x 5 replicates). RW with dimensions of 35 mm long x 28 mm wide × 3 mm thick was used as feeder strip for inoculation of *P. sanguineus*. The steam sterilised particleboard samples were put on the feeder strips covered with mycelia and put on the top of the soil in each culture bottle. The test blocks were incubated for 16 weeks. At the end of the test, the samples were removed from culture bottles. The test blocks cleaned from fungal mycelium were then oven-dried until constant weights were attained. Each block was weighed and the percentage of weight loss for the test block was calculated using the Equation (2):

$$WL\ (\%) = 100\ (W_i - W_f)/W_i \qquad (2)$$

where W_i is the initial weight of test block before exposure to fungi (g) and W_f is the weight of test block after exposure to fungi (g).

RESULTS AND DISCUSSION

Colour Changes

The visual appearances of both the RW and OPT particleboard after treated at different treatment temperatures are shown in *Figure 1*. Heat-induced darkening can be observed on the sample surfaces and the extent of darkening increased along with increasing treatment temperature. Alteration of wood colour due to thermal treatment could be caused by the migration of quinonnes, extractives, low molecular sugars and amino acids towards the samples' surfaces (Bekhta and Niemz, 2003). Salca *et al.* (2016) attributed the heat-induced colour changes to the degradation of lignin and hemicelluloses. Apart from that, oil uptake is also a factor that can contribute to the darkening effect of the samples as it forms an oil layer on the wood surface. Dubey *et al.* (2011) found that wood with higher oil uptake tended to have darker colour. Toker *et al.* (2016) suggested that, in a treating medium without presence of oxygen, caramelisation of soluble sugars produced from hydrolysed hemicellulose imparted darker colour to the wood.

The untreated OPT particleboard has lightness (L*) of 59.93, coordinate green-red (a*) of 2.75 and coordinates blue-yellow (b*) of 6.40. Meanwhile, the RW particleboard had the respective values of 47.44, 0.41 and 5.51. Average colour coordinates (ΔL*, Δa*, Δb*) and colour changes (ΔE*) as a result of heat treatment are tabulated in *Table 1*. Decrement in lightness (ΔL*) indicated the darkening effect induced by heat treatment. Lightness also represents the extent or severity of the thermal treatment. In this case, OPT particleboard seems to be more affected by the heat treatment as decrement in ΔL*

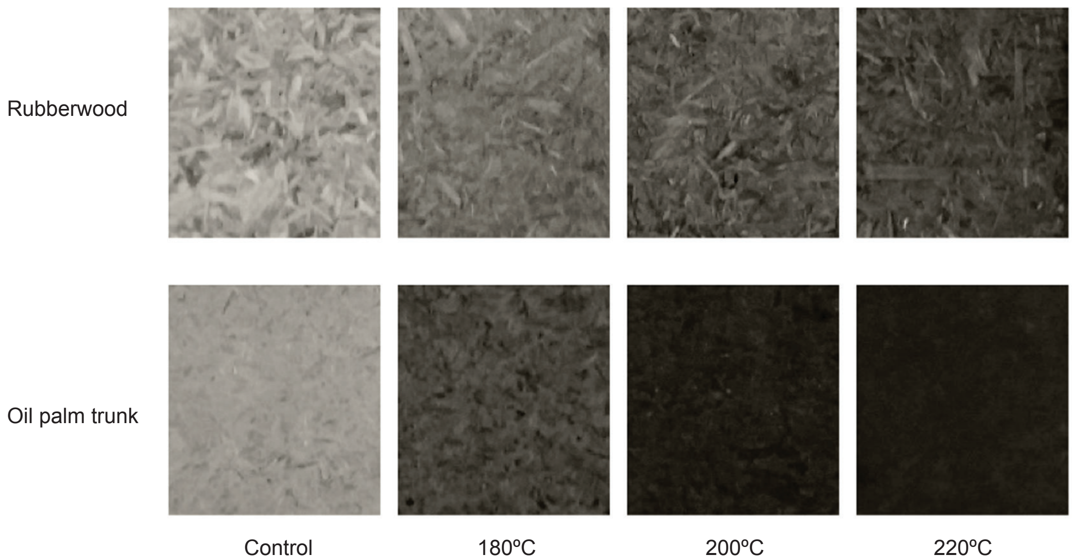

Figure 1. Visual appearance of rubberwood (RW) and oil palm trunk (OPT) particleboard as function of heat treatment temperature.

was higher compared to that of the RW samples. Bektha and Niemz (2003) attributed the reduction in lightness to the degradation of hemicellulose, particularly pentosan.

For both OPT and RW samples, a* and b* values increased when the particleboards were treated at a milder temperature (180°C). However, as the treatment temperature elevated, both values started to decrease and these findings were in line with study reported by Gonzalez-Pena and Hale (2009). Generally, wood becomes redder and more yellow when subjected to heat treatment. RW samples became redder after heat treatment as indicated by the positive a* values. Nevertheless, the reddening effect was attenuated as the treatment temperature increased. On the other hand, the OPT samples basically showed the same pattern as RW samples except it became greener when treated at 220°C, as indicated by negative a* value. Yellowing (positive b* value) was observed as the sample treated at milder temperature and the effects were eventually succeeded by the bluing effects and the treated samples became bluer (negative b* value) when subjected to higher temperature. As a result, total colour changes (ΔE*) for both OPT and RW increased along with increasing treatment temperature. The finding was in agreement with Srinivas and Pandey (2012) who reported similar trend for thermally treated RW and silver oak. In a study reported by Gonzalez-Pena and Hale (2009), the ΔE* is positively correlated with the amount of lignin. As thermal treatment generally increased the lignin content of the wood, ΔE* is increased correspondingly.

Fungal Resistance

Figures 2 and *3* display the visual appearance of the OPT and RW after 16-week exposure to white rot fungi, *Pycnoporus sanguineus*. From *Figure 3*, it can be observed that the RW particleboard sample were fully covered by the white rot fungi. However, for thermally treated particleboard samples, the surfaces were clear of fungal inhibition, indicating that the thermal treatment has prevented the colonisation of fungi on the samples. It is interesting to note that the untreated OPT particleboard samples did not cover by the white rot fungi as RW particleboard did. This observation is well-correlated with the average weight loss of the samples caused by *P. sanguineus* as illustrated in *Figure 4*. The weight loss of the untreated OPT and RW samples were 12.97 ± 1.62% and 30.71 ± 1.75%, respectively. The weight loss reduced as the samples treated at 180°C and the reduction increased along with increasing treatment temperature. At 220°C, the respective weight loss of OPT and RW samples were 4.58 ± 0.44% and 5.78 ± 1.23%. RW showed higher weight loss compared to that of the OPT. This might be attributed to the lower lignin content in OPT compared to RW. *P. sanguineus* is a selective white rot which only digests wood hemicellulose and lignin while leaving cellulose undegraded (Howell *et al*., 2009). OPT was reported to contains 18%-21% lignin (H'ng *et al*., 2011) while RW contains around 24%-27% lignin (Okino *et al*., 2010). Therefore, higher extent of growth was found on RW samples as they provide sufficient nutrient to the white rot fungi. In addition, RW is more hygroscopic in terms of swelling properties than OPT and therefore absorbs more water and creates a favourable environment for the growth of fungus (Sulaiman *et al*., 2012).

Improvement in fungal resistance of the heat-treated wood samples could be attributed to: (i) change in nature of the wood from hydrophilic to hydrophobic, (ii) generation of fungus repressive extractives, (iii) alteration of wood constituents, and (iv) removal of hemicellulose (Kamdem *et al*., 2002). The enhancement in fungal resistance is temperature dependent where the higher the treatment temperature, the lower the mass loss. At higher temperature, higher amount of thermally labile hemicellulose was degraded. The removal of these hydroxyl groups make the wood hydrophobic and the capability of the wood to absorb moisture from the environment is reduced.

TABLE 1. COLOUR ALTERATION OF OIL PALM TRUNK AND RUBBERWOOD SAMPLES INDUCED BY HEAT TREATMENT AT DIFFERENT TREATMENT TEMPERATURES

Species	Treatment temperature (°C)	ΔL*	Δa*	Δb*	ΔE*
Oil palm trunk	180	-30.65	+10.31	+9.21	33.71
	200	-52.25	+8.21	-4.32	53.14
	220	-59.93	-1.40	-5.98	60.23
Rubberwood	180	-22.95	+11.31	+8.11	27.41
	200	-30.96	+13.99	+7.27	34.88
	220	-41.95	+6.31	-4.70	42.75

Note: ΔL* - Lightness, Δa* - green-red, Δb* - blue-yellow, ΔE* - colour changes.

Moisture is the most prominent factor in promoting fungal growth in wood. Most studies have shown that the conversion of hydrophilic nature of wood to hydrophobic through thermal treatment is the key reason for the improved fungal decay resistance (Weiland and Guyonnet, 2003; Li *et al*., 2017). Previous study by Lee *et al.* (2017) revealed that the equilibrium moisture content of the oil heat treated particleboards reduced from 6.75 ± 0.35% to 3.87 ± 0.02% for OPT particleboard and 6.60 ± 0.04% to 4.28 ± 0.29% for RW particleboard. As the hygroscopicity of the samples is reduced, the fungal growth is also expected to be reduced. The main function of moisture exists in wood is to facilitate the transportation of diffusible agents from fungi into the wood cell wall (Thybring, 2013). By excluding or reducing the moisture from wood through thermal treatment, the ingress of fungi into the cell wall was obstructed. Apart from that, the degradation of hemicellulose, generation of toxic substances and increment of acidity of wood during heat treatment are also some probable reasons that contribute to the improvement in fungal decay resistance (Boonstra *et al*., 2007; Wang *et al*., 2018).

Figure 5 displays the relationship between ΔE* and weight loss caused by white rot fungi. A strong positive correlation (R^2 = 0.9327) was found between weight loss and ΔE* of OPT samples. On the other hand, the correlation was less strong (R^2 = 0.7527) for RW samples but still indicated a good correlation between weight loss and ΔE*. The results obtained in this study suggested that weight loss decreased as the ΔE* values increased. Although several reported studies observed a significant correlation between changes in colour and improvement in durability of wood against fungal decay, it is, however, not necessarily accurate. The colour distribution during thermal treatment is not homogenous and uniform (Esteves *et al*., 2008).

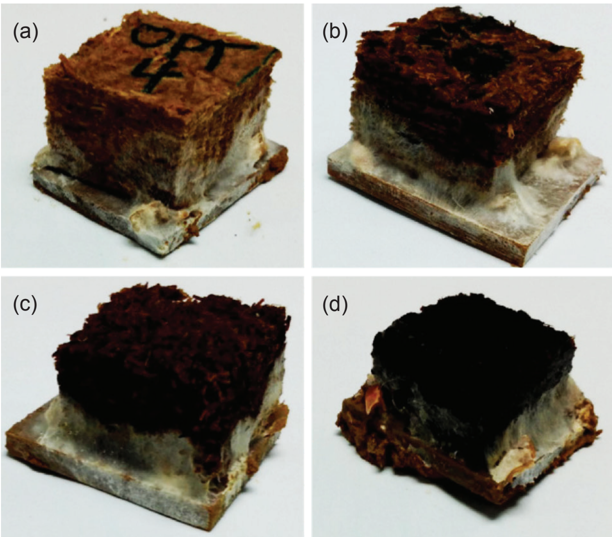

Figure 2. Visual appearance of oil palm trunk (OPT) particleboard treated at (a) control, (b) 180°C, (c) 200°C and (d) 220°C after exposure to Pycnoporus sanguineus.

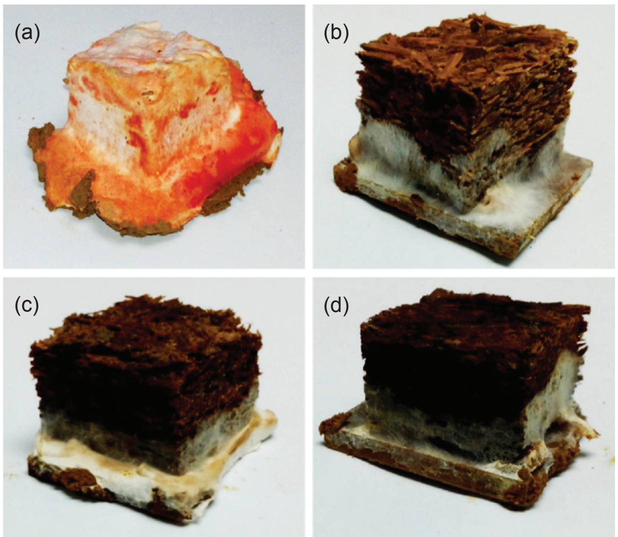

Figure 3. Visual appearance of rubberwood (RW) particleboard treated at (a) control, (b) 180°C, (c) 200°C and (d) 220°C after exposure to Pycnoporus sanguineus.

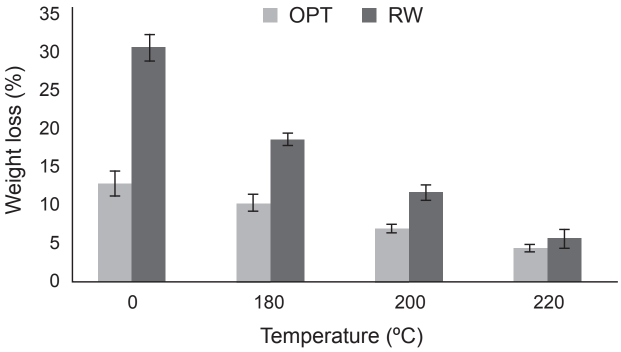

Figure 4. Weight loss of oil palm trunk (OPT) and rubberwood (RW) particleboard after exposure to Pycnoporus sanguineus.

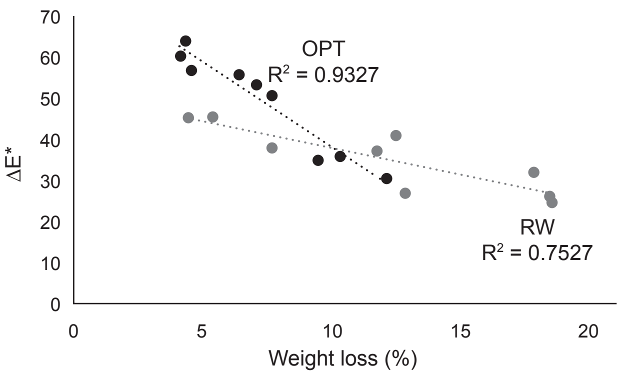

Figure 5. Correlation between weight loss (%) by Pycnoporus sanguineus *and changes in colour (ΔE*) of the particleboard samples treated at different temperatures.*

Although the fungal resistance of the treated samples was improved, it should be noted that the oil presented on surfaces of the treated samples might have adverse effect on the gluability when particleboard panels were to be used for thin overlay materials. However, some treatments could be conducted in order to improve the gluability of the particleboard. Sanding and planning could improve the surface wettability of the samples and therefore improve its bonding performance (Wang and Stirling, 2008). Apart from that, plasma treatment aiming to remove the excessive oils could also be applied to enhance its surface wettability and subsequently lead to better gluability (Jamali and Evans, 2008).

CONCLUSION

Thermally treated particleboard exhibited significant changes in colour and improvement in fungal resistance. Heat-induced darkening can be observed on the sample surfaces and the extent of darkening increased along with increasing treatment temperature. The lightness (L*) of the particleboards reduced after thermal treatment. Generally, particleboard samples become redder and more yellow when subjected to thermal treatment. Nevertheless, when subjected to higher temperature (220°C), the samples become bluer. Improvement in fungal decay resistance were observed as the weight loss of untreated OPT samples reduced from 12.97 ± 1.62% to 4.58 ± 0.44% when treated at 220°C. The treatment effectiveness is temperature dependent as higher treatment temperature resulted in better fungal resistance. RW samples were found to be less resistant to fungal attack compared to that of the OPT samples, probably due to its higher hygroscopicity and higher lignin content that provide more favourable environment for the growth of white rot fungus. Nevertheless, after heat treatment, RW showed better improvement (weight loss from 30.71% ± 1.75% to 5.78% ± 1.23%) than OPT. Strong positive correlations (R^2 = 0.9327 and 0.7527 for OPT and RW, respectively) were found between weight loss and ΔE*, suggested that the fungal resistance improved along with increasing magnitude in ΔE* values. The results suggested that the colour changes could be a reliable prediction tool for the researchers to have a rapid quantification of the extent of decay resistance. However, it should be noted that it is species dependent and further researches for validation are needed.

ACKNOWLEDGEMENT

The authors wish to thank for the financial support provided by Geran Universiti Putra Malaysia (GP) GP/2017/9575500 and Higher Institutions' Centre of Excellence (HICoE), Project code: UPM/INTROP/100-13/9/3/HICoE/6369107.

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