Investigation of the Use of Old Railroad Ties (*Fagus orientalis*) and Citrus Branches (Orange Tree) in the Particleboard Industry

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Effects of two widely available and underutilized lignocellulosic materials on the mechanical and physical properties of particleboards were investigated in this work. The ratio of mixtures lignocellulosic flakes at four levels (100% aspen wood), (50% aspen wood: 25% citrus: 25% old railroad ties), (50% aspen wood: 50% citrus), and (50% aspen wood: 50% old railroad ties), and the percentage of resin in two levels (8 and 12%) were considered as variable factors. The 100% aspen wood (*Populus tremula*) was mixed as a control board (100% aspen wood). Then the mechanical and physical properties of the samples including modulus of rupture, modulus of elasticity, internal bond, water absorption, and thickness swelling after 2 h and 24 h of immersion (EN 310-319) and fire resistance (ISO 11925-2) were measured. The results showed that with increasing poplar wood in mixtures, modulus of rupture, modulus of elasticity, internal bond increased, while water absorption and thickness swelling decreased. Also, in comparison with the control boards, the boards that were made by mixing 50% poplar and 50% citrus branches with 12% glue had the highest mechanical strength. The results also showed that increasing the amount of old railroad ties chips in mixing caused a significant decrease in the fire retardancy of the boards.

Keywords: Branches; Old railroad ties; Particleboard; Resin; Percentage; Modulus of rupture

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INTRODUCTION

Particleboard industries have a special emphasis on the use of waste and lumber, including low-consumption wood species, forest bark residues, and lignocellulosic waste from farms and garden trees. In this regard, identifying new lignocellulosic sources and investigating the possibility of using them to feed particleboard production units has a special priority, and the present research was carried out on this basis. One lignocellulosic material that has recently been considered is old railroad ties. Such lumber comes out from under the rails after 25 years and no longer has any special application in industry. Its volume reaches 180,000 m^3/yr. The amount of such wood is more than commercial species such as beech (*Fagus orientalis*) and hornbeam (*Carpinus betulus*), which are commonly used in fencing around gardens and agricultural lands. Old railroad ties typically are impregnated with oily preservatives (creosote). Another lignocellulosic material used in this study was citrus tree branches, whose annual production reaches 8,000 tons/yr according to the Organization of Agriculture Jihad Mazandaran (Deputy Minister of Planning and Economic Affairs of Jihad-e-Agriculture of Mazandaran). Limitation of wood resources and increasing market demand for particleboard in Iran motivates the use of various lignocellulosic resources such as agricultural waste, tree branches, and waste wood in particleboard. Utilization of such resources is viewed as a step towards job creation in addition to reducing deforestation. In addition to the type of wood raw material and lignocellulose, other factors such as the amount of resin, manufacturing conditions, and the quality of the wood particles themselves also affect the quality of the board. The studies were conducted to investigate the physical and mechanical properties of particleboard. Enayati and Bezaatipour (2000) studied the possibility of making particleboard from old railroad ties located in Karaj to Shirgah. After comparing the physical and mechanical properties of the boards, they found that the boards made of old railroad ties in the Karaj region had a higher physical and mechanical strength than boards made of old railroad ties located in Shirgah. Tabarsa *et al.* (2008) investigated the production of cement wood from old railroad ties. Variable factors in this study were the temperature (60 and 25 °C) of the amount of calcium chloride (2, 5, and 7% dry weight) additive as a coupling material. Their results showed that the boards made at 25 °C and using 7% additive had higher mechanical strength and less water absorption and thickness swelling. The effects of raw material density on the requirements of almond branches and poplar trees were tested with urea-formaldehyde resin (Doosthoseini 2002).

EXPERIMENTAL

Composite Panel Production

About 300 kg from each of the primary sources, including aspen wood (*Populus tremula*), old railroad ties (*Fagus orientalis*), and citrus branches (orange tree) were prepared. For this purpose, old railroad ties were collected from Shirgah Traverse Saturation Factory. Citrus branches and poplar wood were obtained from the gardens of Babol city and transferred to the laboratory of Alborz Research Institute located in Karaj (Fig. 1).

A B C

Fig. 1. Lignocellulosic materials used in this research: (A) aspen wood, (B) citrus branch, and (C) old railroad ties

The raw material was processed using a roller shredder and immediately turned into wood material suitable for particleboard using a ring mill. After removing very fine and very big wood chips that were not suitable for making particleboard, the moisture content of the particleboard was reduced to 1% through a laboratory dryer, and it was packed in moisture-resistant plastic bags and stored for making laboratory boards. For gluing the chips, a laboratory gluing machine was used. The glue solution along with the catalyst

(NH_4Cl) was thoroughly mixed with them. Subsequently, the cake (ingredients: lignocellulosic matrials and resin) from the mixing machine was poured uniformly into a 40 ×40 cm wooden mold. After forming the particle cake, using a Bürkle-LA-160 (Bürkle, Stuttgart, Germany) laboratory press, the particle cake was pressed, and laboratory boards were made.

In this study, two factors, the amount of adhesive in two levels of 8 and 12% (based on the dry weight of wood chips) and the ratio of mixtures lignocellulosic flakes at four levels (100% aspen wood), (50% aspen wood: 25% citrus: 25% old railroad ties), (50% aspen wood: 50% citrus), and (50% aspen wood: 50% old railroad ties) were considered as variable factors in this study and other conditions including the type of the glue (urea-formaldehyde). Information of glue is given in Table 1. The following treatment conditions were kept constant in this work: press heat (130 °C); board thickness (16 mm); pressure board weight (0. 7 kg/cm^3); and press pressure (30 kg/cm^2). After the end of the press, to ensure uniformity of line moisture and balance the internal stresses, the boards were stored in the laboratory for 15 days. Mechanical properties [modulus of rupture (MOR) (EN 310 1993), modulus of elasticity (MOE) (EN 310 1993), and internal bond strength (IB) (EN 319 1993)] and physical properties [thickness swelling (TS) and water absorption (WA) (EN 317 1993)] were determined for the produced particleboards.

Table 1: Information of the Urea- Formaldehyde Resin

Performances	Information
solid content	55.5 (%)
free formaldehyde content	39,77 (%)
viscosity	51.69 (mPa·s)
curing time	90 (s)
hot-press temperature	130 °C

The load and deflection were continuously recorded, and the data were used to calculate MOR, MOE, and IB based on Eqs. 1, 2, and 3,

$$MOR = 1.5 \times (FL / bd^2) \quad \text{(Mpa)} \tag{1}$$

$$MOE = FL^3 / 4bd^3D \quad \text{(Mpa)} \tag{2}$$

$$IB = F / A \quad \text{(Mpa)} \tag{3}$$

where F is the maximum force (N), L is the span length (mm), b is the sample width (mm), d is the sample thickness (mm), D is the deflection, and A is the sample cross section (mm^2).

Physical Tests

The effect of composite formulation on the water absorption (WA) and thickness swelling (TS) after 2 and 24 h immersion in water was determined in samples with the dimensions of 50 mm × 50 mm × 20 mm according to DIN EN 634-1 and 2 (DIN 1995). The sample was then soaked in distilled water for 2 h and 24 h. Water absorption and TS were then calculated according to Eqs. 4 and 5,

$$WA\,(\%) = [\,(W_2 - W_1) / W_1] \times 100 \tag{4}$$

$$TS = [\,(T_2 - T_1) / T_1] \times 100 \tag{5}$$

where *WA* is water absorption (%), W_1 is dry mass before immersing (g), W_2 is wet mass after each immersing (g), *TS* is thickness swelling (%), T_1 is thickness before immersing (g), and T_2 is thickness after each immersion (g).

Fire-Retardant Testing Apparatus

The 150 mm × 100 mm × 20 mm boards were prepared according to ISO 11925 (2010) specifications for the fire resistance tests (Fig. 2). To test for the mass loss of the samples due to fire exposure the specimen was vertically mounted on a holder up-straight and exposed to a Bunsen-type burner (with an internal diameter of 11 mm) held at 45° to the surface of the specimen for 120 s in accordance with the method described by Esmailpour *et al*. (2017). The weight was measured before and after the test to measure the weight loss percent.

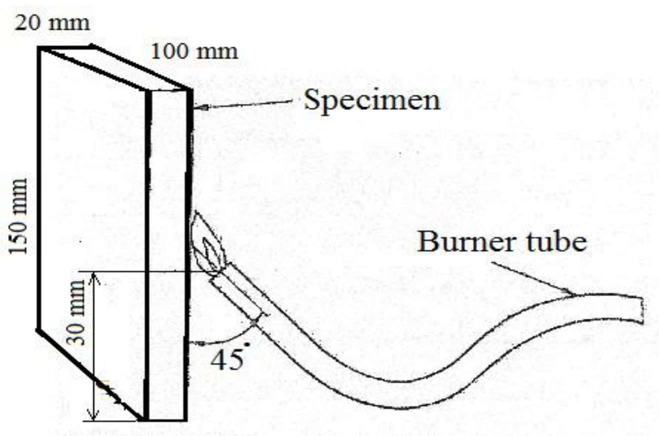

Fig. 2. Schematic of the fixed fire testing apparatus

Statistical Analyses

Statistical analyses were performed using Statistica software v.13 (Dell Inc., Round Rock, TX 2016). The obtained results were analyzed statistically, and an analysis of variance (ANOVA) was performed to determine the significance of the tested parameter. A Duncan's multiple range test (DMRT) was performed to compare treatment means.

RESULTS AND DISCUSSION

Mechanical Properties

The results from the mechanical testing are shown in Figs. 3, 4, and 5. The result indicated that increasing the old railroad ties chips in the mixture significantly decreased the MOR, MOE, and IB values of the particleboards. Adding aspen wood chips from 25% to 50% significantly increased the MOR, MOE, and IB values of the particleboards. Similar results were reported by Enayati and Bezaatipour (2000). The highest MOR, MOE, and IB values were found in the control samples (100% aspen wood) and the mixture of (50% aspen wood 50% citrus branch) with 12% resin content. The lowest mechanical properties particleboard was in the mixture of (50% citrous branch 50% old railroad ties) with 8% resin content (Figs. 3, 4, and 5). It is important to note that mechanical strength in boards that were made with 12% resin was significantly higher than panels made with 8% resin. This can be related to the positive effect of resin increment on mechanical strength (Kasim *et al.* 2001; Nacer *et al.* 2005; Pan *et al*. 2007; Ashori and Nourbakhsh 2008). Aspen wood is an excellent raw material for manufacturing particleboard. One of the reasons that caused the mechanical strength to improve with increasing aspen wood in the mix is its low density; aspen wood chips increased the compression ratio of the boards during pressing. This increased the mechanical strength of the boards. Decreasing mechanical properties with increasing old railroad ties chips in the mixture can be due to the oily properties of the chips, which made the adhesive not stick to the chip. The same results were reported in a previous study (Bazyar *et al*. 2011).

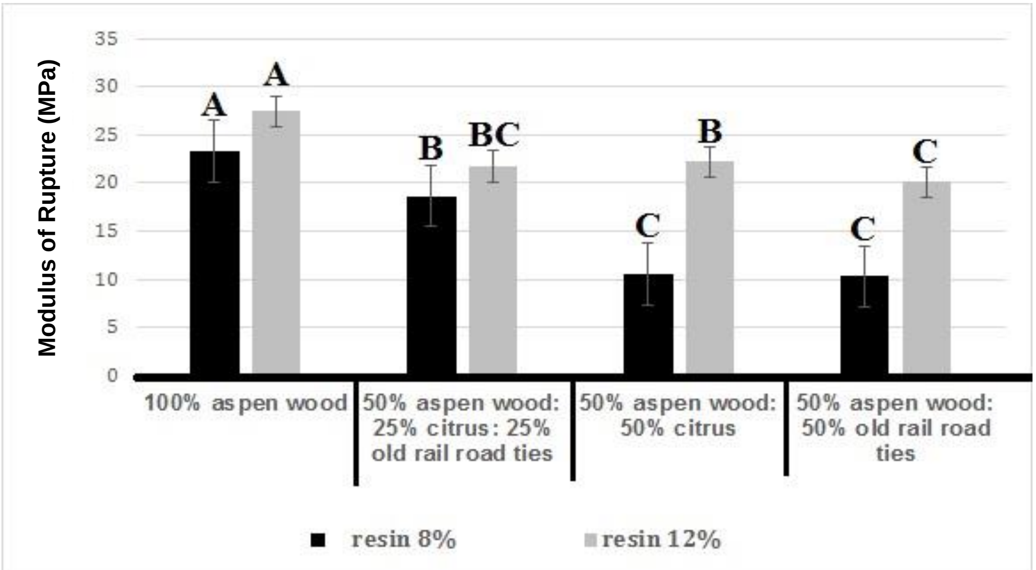

Fig. 3. MOR Strength particleboard made from aspen wood: citrous branch: old railroad ties contents (letters on each column indicate Duncan's grouping at the 99% level of confidence)

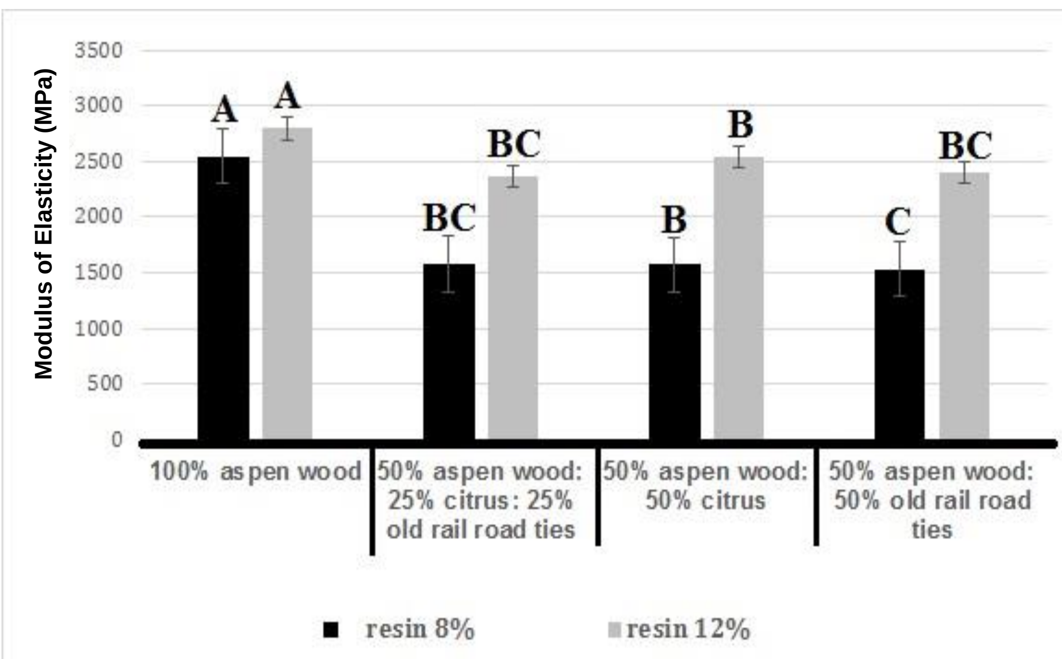

Fig. 4. MOE Strength particleboard made from aspen wood: citrous branch: old railroad ties contents (letters on each column indicate Duncan's grouping at the 99% level of confidence)

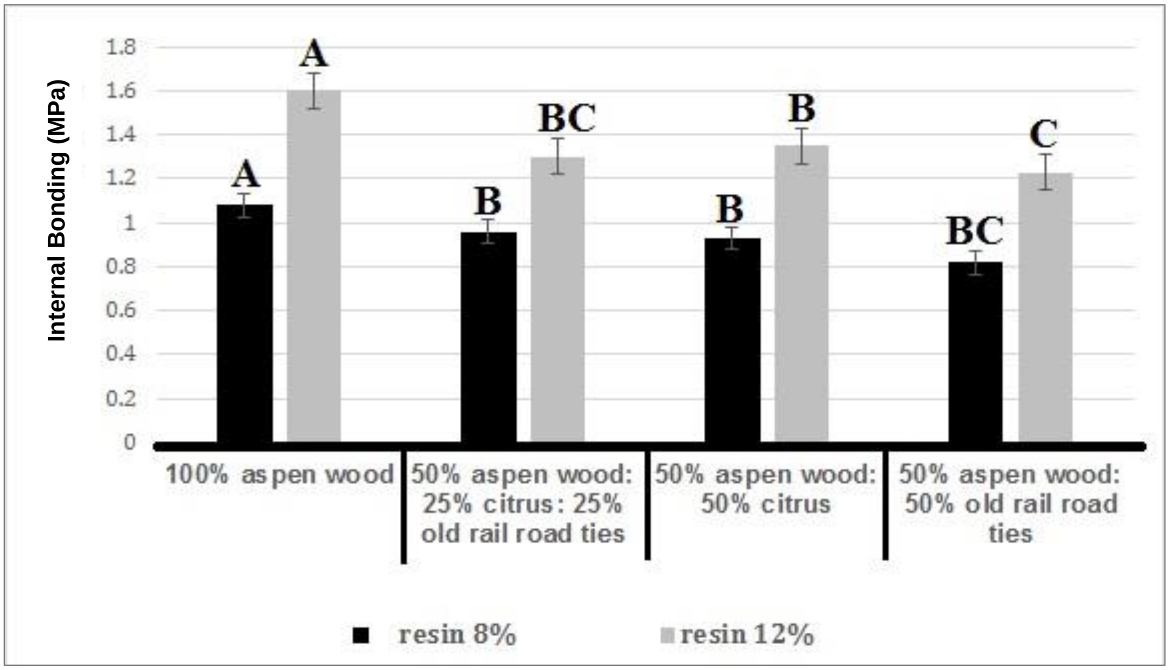

Fig. 5. IB Strength particleboard made from aspen wood: citrous branch: old railroad ties contents (letters on each column indicate Duncan's grouping at the 99% level of confidence)

Physical Properties

The physical properties of the panels evaluated were water absorption, thickness swelling after 2 and 24 h immersion in water, and fire resistance (mass loss). The results of these tests are presented in Figs. 6, 7, and 8.

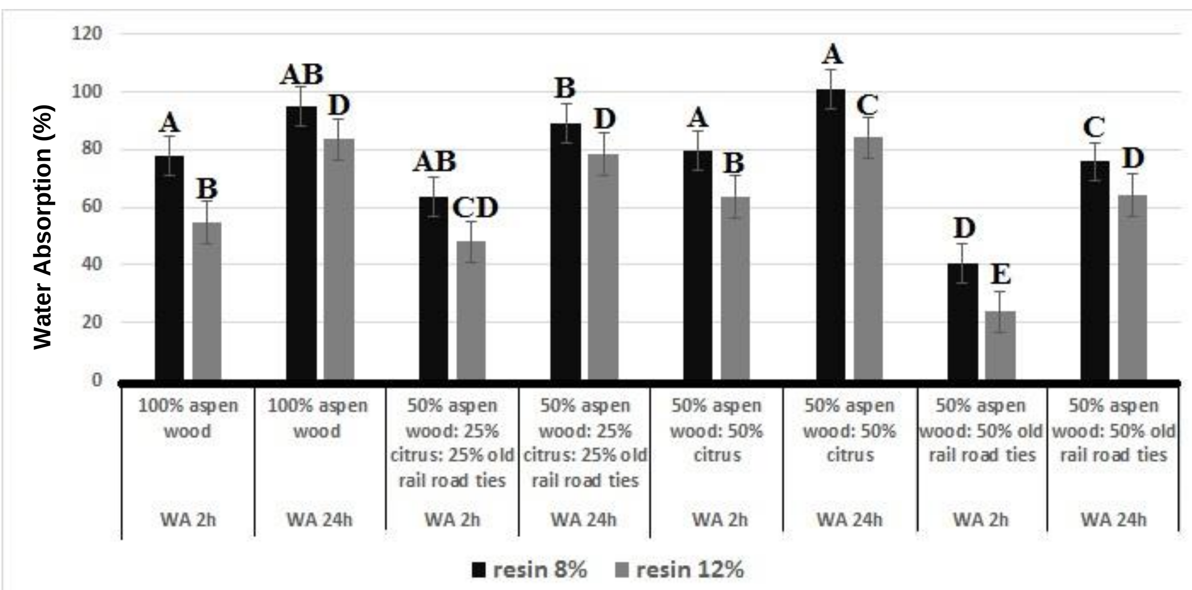

Fig. 6. Water absorption (%) after 2 and 24 h particleboard made from aspen wood, citrous branch, and old railroad ties contents (letters on each column indicate Duncan's grouping at the 95% level of confidence)

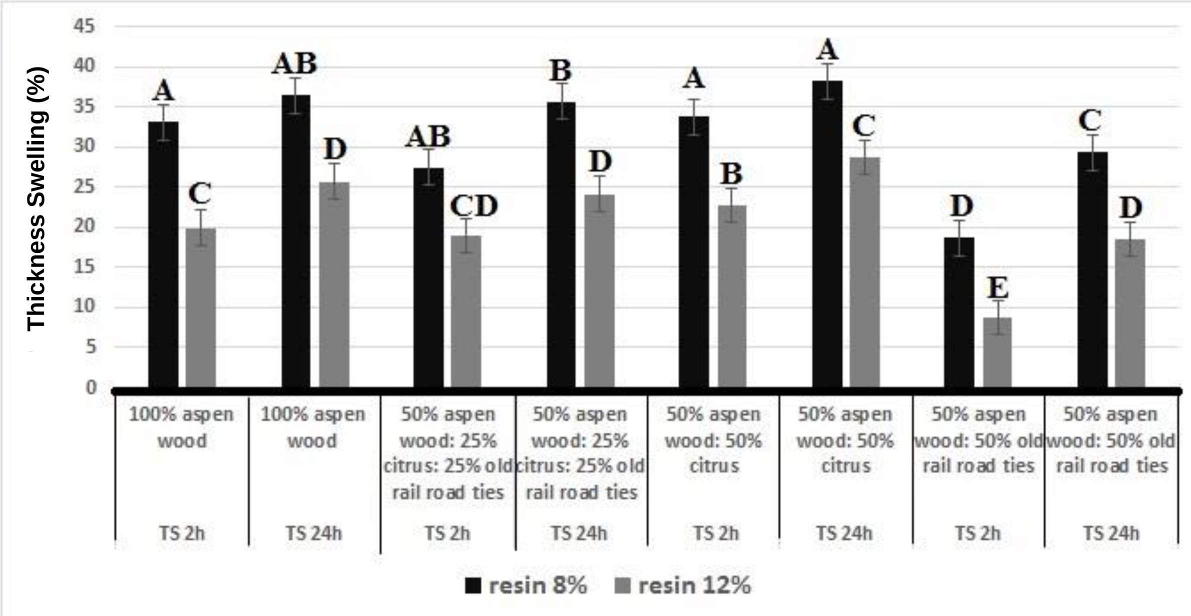

Fig. 7. Thickness swelling (%) 2 and 24 h particleboard made from aspen wood, citrous branch, and old railroad ties contents (letters on each column indicate Duncan's grouping at the 95% level of confidence)

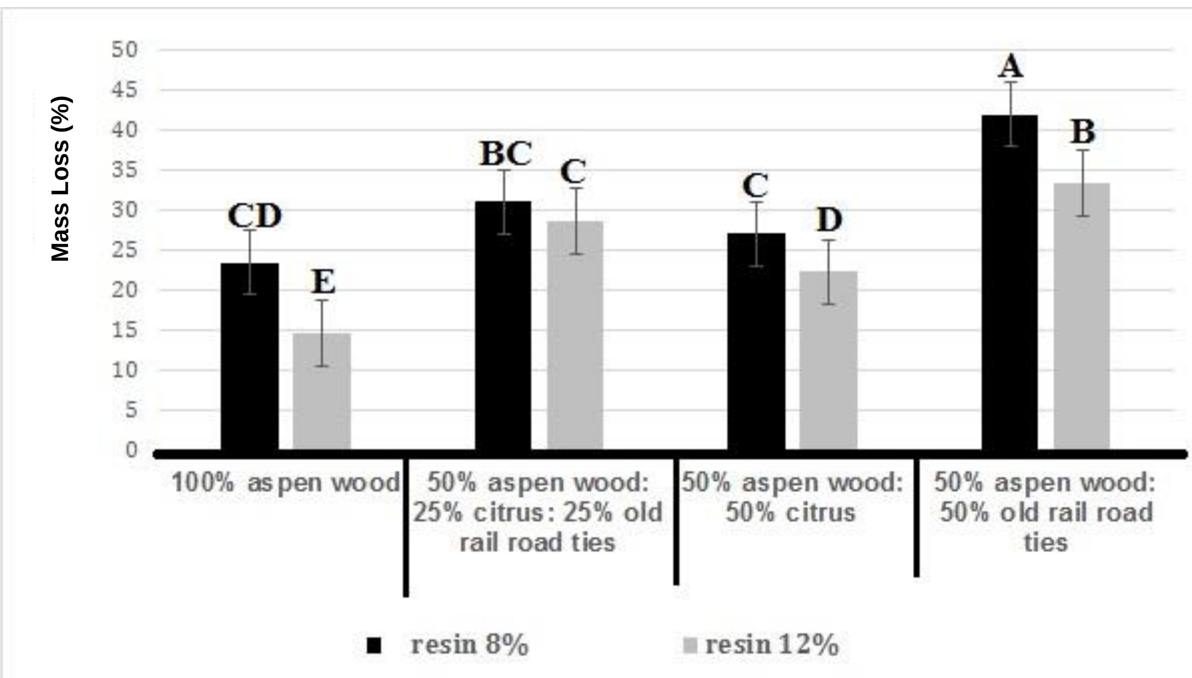

Fig. 8. Mass loss (%) particleboard made from aspen wood, citrous branch, and old railroad ties contents (letters on each column indicate Duncan's grouping at the 99% level of confidence)

The water absorption and thickness swelling improved with each increment of the amount of old railroad ties in the panels. Also, results showed that increments of resin content from 8% to 12% had a significant effect on all physical properties of boards. With more resin, more bonding sites were made available, thereby increasing the dimensional stability of boards. The lowest water absorption and thickness swelling were observed in boards containing 50% aspen wood and 50% old railroad ties with 12% resin content (Figs. 6 and 7). It seems that the hydrophobic characteristic of creosote in waste wood can be related to the decrease of WA and TS in the samples that are made with more old railroad ties chips.

The highest water absorption and thickness swelling was found in the mixture of 50% aspen wood and 50% citrus with 8% resin content (Figs. 6 and 7). The results indicated that the fire-retarding properties of the boards were decreased by the addition of old railroad ties chips in the mixture (Fig. 8). The lowest mass loss was observed in control samples (100% aspen wood) and the mixture of 50% aspen wood and 50% citrus with 12% resin content (Fig. 8). Boards made of aspen wood have a higher density due to the higher compression coefficient during pressing. These boards have a high heat transfer, and their heat is not kept at a single point and is rapidly transferred to a point where it has less heat thus reducing the fireproof ability of boards and increasing their fire resistance. Because the wood chips made of old railroad ties were impregnated with an oily preservative, they burn quickly against a flame, which makes old railroad ties less resistant to fire.

CONCLUSIONS

1. Mechanical and physical properties of particleboards mixed with aspen wood, citrus branch, and old railroad ties were examined, and the results indicated that the reduced content of aspen wood chips and their replacement with either old railroad tie chips or citrus wood chips had a significant decreasing effect on modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB).
2. Due to its low density, aspen wood chips increased the compression ratio of the boards during pressing. This property increased the mechanical strength of the boards.
3. Old railroad ties significantly decrease water absorption and thickness swelling. hydrophobic characteristic of creosote in waste wood can be related to the decrease of WA and TS in the samples that are made with more old railroad ties chips.
4. Adding old railroad ties chips from 25% to 50% significantly decreased the fire resistance of the particleboards because the wood chips made of old railroad ties were impregnated with an oily preservative. This caused the chips to burn quickly against a flame.

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