ISSN: 2692-5397

Modern Concepts in Material Science

DOI: 10.33552/MCMS.2024.05.000646

Iris Publishers

Research article

Manufacturing Thermoplastic Particleboards by Compounding Hotmelt and Wood Chips Using a Rotational Heat Mixer

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Received Date: October 14, 2024

Published Date: December 02, 2024

Abstract

This study focuses on the development of an efficient method for manufacturing thermoplastic particleboards. The aim of this investigation was to identify a process that ensures uniform wetting of wood particles with an aspect ratio of 5:1 and a length of 7 mm. Polyolefins, including unfilled polypropylene (PP), were used as hotmelt binders in varying weight proportions from 10% to 30%. Conventional extrusion methods proved unsuitable due to high tool wear and undesired fragmentation of the wood chips. In contrast, a rotational heat mixer was favored, which, through its rotational movement, creates a wiping and smearing effect that promotes uniform distribution of the molten hotmelt over the wood particles. This innovative process enabled the production of high-quality, homogeneous, and dimensionally stable particleboards with significantly improved physical properties.

Keywords: Manufacturing process; Thermoplastic particleboards; Rotational heat mixer; Wood chips; compounding; Water absorption

Introduction

Traditional particleboards are typically manufactured using urea-formaldehyde resins as binders, which pose significant health and environmental challenges [1]. These resins are not only potentially harmful to human health but also greatly limit the recyclability of the boards [2,3]. A promising alternative is the use of thermoplastic hotmelt binders. The application of these materials largely overcomes the disadvantages of conventional resins [3,4]. Thermoplastic particleboards offer the advantage of being reformable at elevated temperatures and efficiently recyclable at the end of their life cycle [4]. However, a major technical challenge in the production of these boards is ensuring the uniform wetting of the wood particles by the molten hotmelt, which directly affects the homogeneity, mechanical, and physical properties of the final product.

Wood-plastic composites (WPCs) represent a relatively new class of composite materials compared to conventional particleboards and have emerged as a growing and promising sector in both the wood and plastic industries [5]. WPCs typically consist of a mixture of wood components, mostly wood flour, and thermoplastic polymers, which are processed into boards under heat and pressure [6]. The dominant manufacturing technologies for WPCs are extrusion and injection molding [7]. However, both processes present specific challenges, particularly with regard to increased tool wear caused by the abrasive properties of wood particles [8]. Furthermore, in the extrusion process, the mechanical fragmentation of wood particles, originally around 7 mm in length, leads to a reduction in particle size, compromising the desired mechanical properties. The particle size of the wood material plays a critical role in optimizing the mechanical properties of these composites [9]. Chen et al. demonstrated in a previous study that larger wood particles significantly increase the bending strength and reduce the density of the composite material [9].

Given these challenges, the aim of this study was to develop and evaluate an alternative manufacturing process that leverages the advantages of large wood chips and a thermoplastic binder to achieve optimal mechanical and physical properties through homogeneous distribution and effective wetting of the wood particles while keeping the hotmelt content as low as possible.

Materials and Methods

Materials:

Spruce wood chips with an average length of 7 mm and an aspect ratio of 5:1 were used. A sieve analysis was conducted using a RETSCH vibratory sieve, yielding the following mesh sizes:

- Over 3.15 mm: max. 5%
- Over 1.25 mm: max. 85%
- Over 0.2 mm: min. 99.5%

The bulk density was 150 g/L, and the pH value ranged between 5 and 7. The chips were dried in an oven at 110°C for 10 hours to ensure moisture content below 5%, thereby promoting consistent adhesion between the wood particles and avoiding negative effects due to high moisture content.

Two different hotmelt binders, both based on polyolefins, were tested for compounding. The first hotmelt binder was a polyolefin blend in granule form with the following properties:

- Softening point (Ring & Ball): ~150°C
- Viscosity (Brookfield) at 180°C: ~15,000 mPa·s
- Heat resistance: ~110°C

Unfilled polypropylene (PP) in granule form was also used as a binder. Its properties were:

- Softening point (Ring & Ball): ~134°C
- Viscosity (Brookfield) at 180°C: ~9,000 mPa·s
- Heat resistance: >95°C

Potential Manufacturing Processes and Experimental Setup

Extrusion Process:

In the extrusion process, wood chips and molten binder are continuously mixed and extruded through a die. Due to the high cost of machinery and the expected mechanical fragmentation of the large wood particles during processing, the extrusion method was not further pursued in this study.

Centrifugal Process:

In the centrifugal process, compounding was carried out using a high-speed ring mixer, where the wood chips are pressed against the outer wall of the mixing chamber by centrifugal force, ensuring uniform distribution. The binder or hotmelt is introduced directly into the rotating chamber via a hollow shaft, a process referred to as internal glue application in wood processing. The centrifugal force ensures that the hotmelt is immediately spread over the wood chips, forming a thin, uniform coating. The fast rotation minimizes the formation of glue filaments or clumps. Mixing times of 5, 10, 15, 20, and 30 minutes were tested to analyze the influence of mixing time on the homogeneity of the mixture.

Spray Process:

In the spray process, the adhesive was applied using a Baumer HHS nozzle model HM500, where the hotmelt was finely and evenly sprayed onto the wood chips while they rotated in a heat mixer. The rotation ensured continuous movement and even distribution of the wood chips. The hotmelt was atomized and sprayed onto the rotating wood chips. This method allowed for a fine, even coating of each chip with a thin layer of adhesive. Mixing times of 5, 10, 15, 20, and 30 minutes were tested to assess the effect of mixing time on mixture homogeneity.

Rotational Heat Mixer:

A rotational heat mixer combines rotation and heating to uniformly mix materials such as wood chips and adhesives. The chips are pushed against the outer wall of the mixer by centrifugal force, while the heating system melts or heats the binder. This ensures a uniform distribution of molten adhesives on the particles. The wiping effect generated by rotation ensures a homogeneous coating without fragmenting the particles. Mixing times of 5, 10, 15, 20, and 30 minutes were tested to evaluate the influence of mixing time on mixture homogeneity. Compounding of the wood chips and polyolefins was performed at temperatures between 160°C and 200°C.

Pressing Process:

The pressing cycle included a maximum pressing temperature of 190°C, a specific pressure of 5 N/mm^2, and a pressing time of 5 minutes. This was followed by a cooling phase, in which pressure was maintained for 10 minutes to allow the boards to cool slowly and minimize internal stresses.

Characterization Methods:

Standardized methods were used to characterize the physical properties of the produced boards, including water absorption (WA), thickness swelling (TS), and moisture content. These parameters offer valuable insight into mixture homogeneity and are also key indicators for modern WPC materials. Both values are highly correlated with other mechanical properties.

Water absorption was measured according to DIN EN 15534-1. Samples measuring 100 × 100 × 10 mm were submerged in water at 20 ± 2°C for 28 days. The samples were dried and weighed before and after submersion to calculate the water absorption percentage.

Thickness swelling was also measured following DIN EN 15534-1. The thickness of the samples was measured before and after 5 hours of hot water immersion. Thickness swelling was expressed as a percentage of the original thickness, providing insight into how much the boards swell upon contact with water—a critical factor for outdoor applications.Microscopic examinations provided initial insights into the distribution of the polypropylene, but the material tests were more decisive, as they directly reflect the mechanical properties and quality of the boards.

Results and Discussion

Table 1: Visual Impression and Initial Comparison of Processes.

Process	Limitations
Extrusion	Significant tool wear and substantial fragmentation of wood chips, resulting in WPC-like properties. Due to the reduction of the chips to almost wood flour size, this process was excluded from further trials. Additionally, large-scale extruders in laboratory conditions are difficult to implement and result in inhomogeneous mixtures.
Centrifugal Process	Minimal fragmentation of wood chips (~5%); however, issues with uneven glue application due to inconsistent centrifugal forces. Problems with glue filaments formation were observed.
Spray Process	Tendency to form glue filaments (fine adhesive strands); difficulties with uniform wetting of the wood chips. Although chip fragmentation was minimal (~5%), the fine spray application caused localized damage to the chips, negatively affecting the mechanical properties of the boards.
Rotational Heat Mixer	Simple process with efficient wiping effect, ensuring uniform distribution of the adhesive. Fragmentation of the wood chips remained minimal (~5%).

Water Absorption and Thickness Swelling:

The goal of this series of experiments was to evaluate water absorption as an indicator of the quality of the produced boards and the efficiency of the manufacturing processes. By comparing the different mixing methods (rotational heat mixer, spray process, and centrifugal process), the homogeneity of the mixtures and their impact on the water resistance of the boards were determined. Lower water absorption is an indicator of better adhesive distribution and a denser, more homogeneous board structure, which is particularly important for applications in moist environments. The mixing time was considered a critical factor, as it significantly influences the homogeneity of the adhesive distribution and, consequently, the water resistance.

Water absorption was measured based on different mixing times (5 to 30 minutes) to analyze the effect of mixing time on the water resistance of the boards. Two different hotmelts (a polyolefin blend and unfilled polypropylene) and two concentrations (10% and 30%) were used to investigate the influence of binder type and content. This ensured that the assessment of the processes was not dependent on specific material combinations but that their efficiency could be reproduced under various conditions.

The diagram shows the water absorption in percentage over various mixing times (in minutes) for different combinations of processes, hotmelts, and weight fractions. The abbreviations for the test conditions are as follows:

- RM: Rotational Heat Mixer
- SE: Spray Process
- ZF: Centrifugal Process
- PP: Polypropylene as binder
- PE: Polyolefin (Polyethylene and Polypropylene) as binder
- _10: 10% binder weight fraction
- _30: 30% binder weight fraction

The diagram figure 1 reveals several important findings regarding the influence of mixing time, binder type, and process on the water absorption of the boards. First, the trends in water absorption are similar for both hotmelt variants. Polypropylene consistently shows slightly lower water absorption compared to polyolefin, indicating its superior water resistance. However, this difference remains constant across all processes, suggesting that the choice of process is independent of the specific hotmelt composition.

As expected, a higher hotmelt content (30% compared to 10%) significantly improves water resistance, as a larger amount of binder better encapsulates the wood chips and reduces water absorption. This trend is also consistent across all processes, indicating that, at longer mixing times, the process itself has less influence on the results, with the hotmelt concentration being the decisive factor.

The analysis of mixing times shows that the optimal mixing time for both the centrifugal process (ZF) and the rotational heat mixer (RM) is around 15 minutes, as no significant changes in water absorption occur after this duration. The changes after 15 minutes are minimal. In contrast, the spray process shows a stabilization of water absorption after just 5 minutes, indicating a faster achievement of homogeneity. This suggests that the spray process could be a more efficient method when shorter mixing times are advantageous.

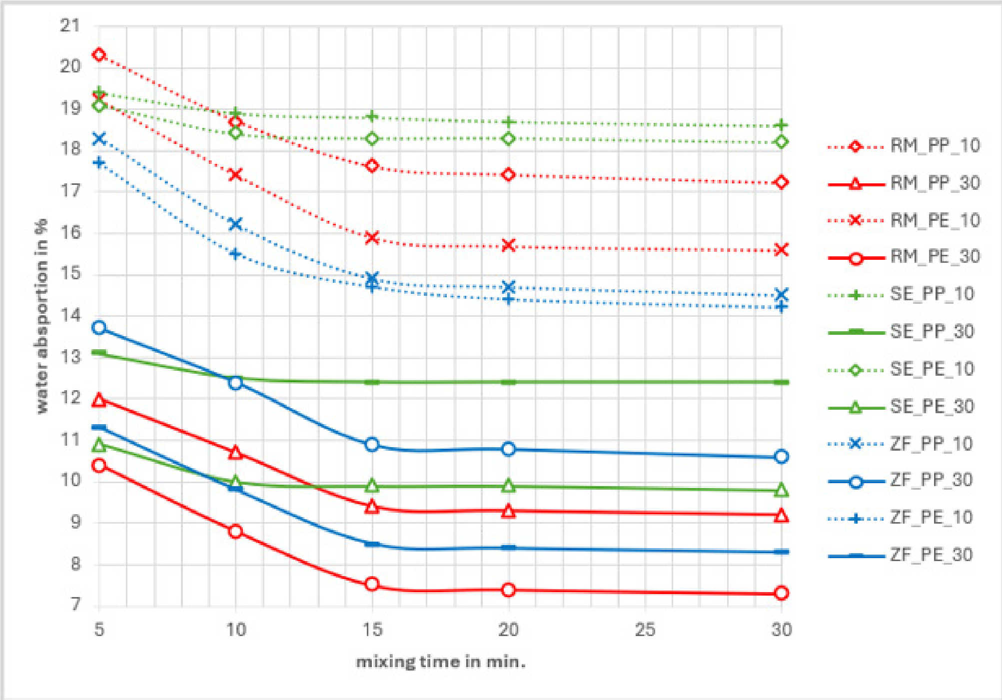

Figure 1: Water Absorption over Mixing Time.

The best result in terms of the lowest water absorption was achieved with the rotational heat mixer (RM) at a 30% hotmelt fraction. This confirms that the rotational heat mixer, with a higher binder concentration and a 15-minute mixing time, provides optimal results in terms of water resistance.

In summary, both binder type and concentration play an important role in water absorption, while the process itself has less influence, particularly at longer mixing times. The rotational heat mixer, with 30% polypropylene and a mixing time of 15 minutes, proves to be the most effective combination for minimizing water absorption.

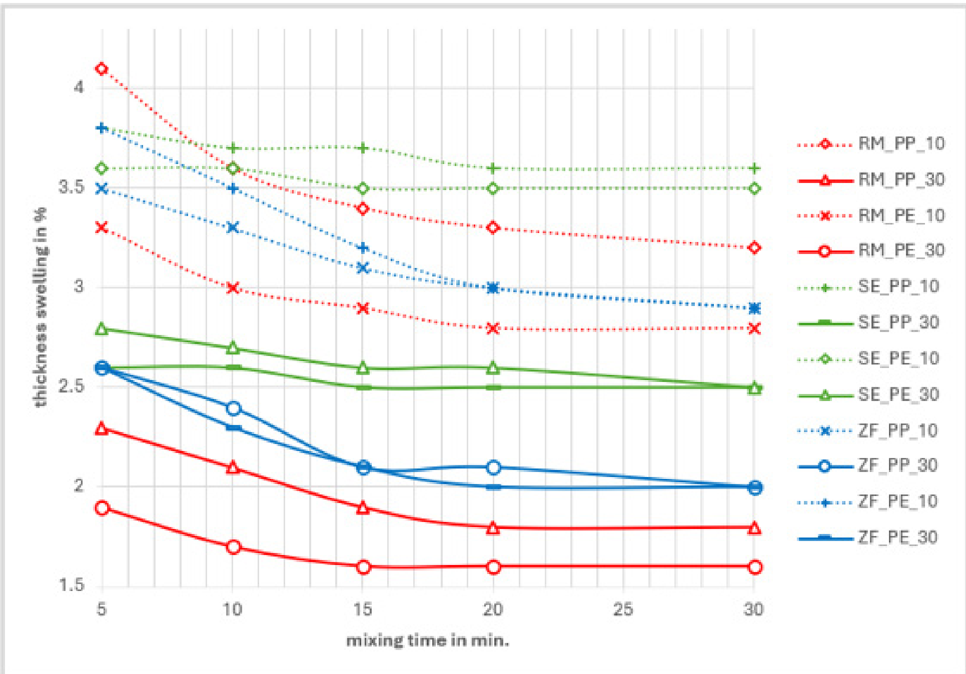

Figure 2: Thickness Swelling over Mixing Time.

The diagram figure 2 on thickness swelling shows similar trends to those for water absorption, but the results are slightly less precise in distinguishing the differences between processes and mixing conditions. Overall, it can be observed that polypropylene (PP) consistently leads to lower thickness swelling compared to polyethylene (PE). This difference remains constant across all processes, indicating that process choice is also less dependent on the hotmelt composition.

Additionally, increasing the hotmelt content from 10% to 30% results in improved water resistance and lower thickness swelling, as expected. This trend is consistent across the various processes, confirming that higher binder content reduces the swelling tendency of the boards, regardless of the technology used.

With respect to mixing times, it was found that for both the centrifugal process (ZF) and the rotational heat mixer (RM), no significant changes in thickness swelling occurred after 15 minutes, suggesting that optimal homogeneity was reached at this time. In the spray process, results stabilized after just 5 minutes, indicating that this method achieves uniform binder application more quickly. The best result was again achieved with the rotational heat mixer (RM) at a 30% hotmelt fraction. However, the differences between the processes were not as pronounced as they were for water absorption.

Conclusion

The present study confirms that compounding wood chips with thermoplastic binders using a rotational heat mixer is a particularly effective method for producing particleboards with optimized physical properties. Compared to traditional methods such as extrusion, the spray process, and the centrifugal process, the rotational heat mixing method demonstrated clear advantages in terms of uniform binder distribution, minimal fragmentation of wood chips, and the resulting improved water resistance and dimensional stability of the boards.

It was demonstrated that with a 15-minute mixing time in the rotational heat mixer, homogeneous distribution of the hotmelt was achieved, significantly reducing water absorption and thickness swelling. This effect was independent of the binder used (polypropylene or polyethylene) and the binder concentration, although higher hotmelt content (30%) yielded better physical properties, as expected. Notably, even with a low hotmelt content of 10%, the boards exhibited impressive performance in terms of moisture absorption and thickness swelling. This low binder content is particularly significant because, in traditional wood-plastic composite (WPC) manufacturing using the extrusion process, the binder content typically ranges from 30% to 50%. Achieving such low moisture absorption and thickness swelling with only 10% hotmelt demonstrates the efficiency of the rotational heat mixer in ensuring effective wetting and distribution of the binder, resulting in robust physical properties despite the lower thermoplastic content.

The spray process, while achieving faster stabilization of water absorption and thickness swelling, did not match the material quality obtained with the rotational heat mixer. The extrusion process proved unsuitable due to significant wood chip fragmentation and poorer homogeneity of the material.

These results underscore that the rotational heat mixer, with its gentle yet efficient processing method, is ideal for manufacturing particleboards, especially where high mechanical stability and water resistance are required. The controlled rotational movement and uniform wiping effect of the process ensure that the thermoplastic binder adequately coats the wood chips without breaking them down, resulting in an improved final product structure.

Future research should aim to further refine the rotational heat mixing method by optimizing variables such as hotmelt composition, temperature profiles, and mixing speed and duration. Additionally, detailed investigations into the interactions between wood chips and different thermoplastic binders could provide valuable insights into further improving the physical and mechanical properties of the particleboards. It would also be worthwhile to explore new mixing dynamics and innovative additives to enhance the durability and resistance of the boards to external influences such as moisture or mechanical stress.

Acknowledgment

This research was supported by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) under the ZIM program. The authors would also like to thank the Niederrhein University of Applied Sciences for their support.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

1. Baumann MGD, Lorenz LF, Batterman SA, Zhang GZ (2000) Aldehyde emission from particleboard and medium density fiberboard products. Forest Products Journal 50(9): 75-82.
2. Wiglusz R, Nikei G, Igielska G, Sitko E (2002) Volatile organic compounds emissions from particleboard veneered with decorative paper foil. Holzforschung 56: 108-110.
3. Bayerischen Landesamt für Umwelt (LfU) (2015) Untersuchung von Spanplatten vor dem Hintergrund der stofflichen Verwertung von Altholz. Ref. 31 / Elke Reichle, März 2015.
4. Stanaszek-Tomal E (2022) Recycling of Wood-Polymer Composites in Relation to Substrates and Finished Products. Building Materials Engineering, Faculty of Civil Engineering, PK Cracow University of Technology.
5. Partanen A, Carus M (2016) Wood and natural fiber composites current trend in consumer goods and automotive parts. Reinforced Plastics 60(3): 170-173.
6. Clemons C (2002) Wood-plastics composites in the United States: The interfacing of two industries. Forest Product Journal 52(6): 10-18.
7. Ayrilmis N, Benthien JT, Thoemen H, White RH (2012) Effects of fire retardants on physical, mechanical, and fire properties of flat-pressed WPCs. European Journal of Wood and Wood Products 70(1-3): 215-224.
8. Zhu Z, Buck D, Wang J, Wu Z, Xu W, et al. (2022) Machinability of Different Wood-Plastic Composites during Peripheral Milling. Materials 15(4): 1303.
9. Chen HC, Chen TY, Hsu CH (2005) Effects of Wood Particle Size and Mixing Ratios of HDPE on the Properties of the Composites. Springer-Verlag 64: 172-177.
10. Niemz P, Bächle F, Sonderegger W, Junghans K, Herbers Y (2007) Grundlagen der Holzbe- und Verarbeitung.