Circular Engineering: Coffee Particleboard for Environmental Sustainability

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INTRODUCTION

The implementation of the circular economy has a direct impact on the fight against climate change and waste prevention. Greenhouse gas (GHG) emissions from the extraction of materials, manufacture of building products and construction of buildings are estimated to be between 5% and 12% of total GHG emissions. A more efficient use of materials could result in savings of 80% of these emissions [1-2]. The utilization of waste through Circular Economy strategies, oriented to a more efficient use of resources for the design of new materials is a key research field where the research presented here is framed by focusing on demonstrating the **technological feasibility of manufacturing chipboard using coffee grounds as a complementary raw material** to be exploited in a useful way at an industrial level. According to the Specialty Coffee Association [3], world coffee consumption is estimated at 300 kg/s. Of the portion used for the preparation of the beverage, 82.57% becomes a residue called coffee grounds. Six million tons of this waste are generated daily, catalogued by the European Waste List (EWL) with code 020399 [4]. At present, its final destination is mostly landfill which generates major environmental problems since its high organic composition and high moisture content (≈66%) promotes microbial growth and biodegradation and leaching processes, contributing to the emission of Greenhouse Gases (GHG) [5-6]. In addition, there is a high risk of spontaneous combustion when it accumulates in large quantities, as well as the emission of bad odors due to fermentation processes. On the other hand, the Food and Agriculture Organization of the United Nations (FAO) in its 74th edition of the FAO Yearbook of Forest Products, indicates that in 2020 the global consumption of wood-based particleboard reached 96,084 million m^3, with Europe being responsible for 37,114 million m^3 of this consumption [7]. These data highlight the high demand for this type of products worldwide. Given this scenario, coffee grounds are a promising alternative for the manufacture of particleboards, which have historically used wood as a raw material.

MATERIALS AND METHODS

The preparation of the particleboards was based **on coffee grounds (C)** in a ratio of 25% and 50%, combined with **wood particles (W)** of different sizes: core (max. 20 mm); for the multilayer board surfaces as well as for the single-layer board (1 mm). The coffee grounds were pre-dried in an oven at 105°C for 24 hours. The adhesive used was **urea formaldehyde (UF)** at a concentration of 10 and 15%. The mixing of raw materials and molding of the different types of boards was done manually.

A steel mold designed for this purpose was used to form the board at a pressure of **0,78 MPa** and **100°C** for **10 minutes**, after which the board was allowed to cool for 6 hours at the same forming pressure.

Table 1. summarizes the composition variations used in the manufacture of **250 x 250 x 10 mm** boards.

Table 1. Composition of processed boards.

Type of board	Composition
Single-layer	25C-75W-10UF
	50C-50W-10UF
	25C-75W-15UF
	50C-50W-15UF
Multilayer	25C-75W-15UF-3L-6C-4S
	25C-75W-15UF-3L-4C-6S
	50C-50W-15UF-3L-6C-4S
	50C-50W-15UF-3L-4C-6S

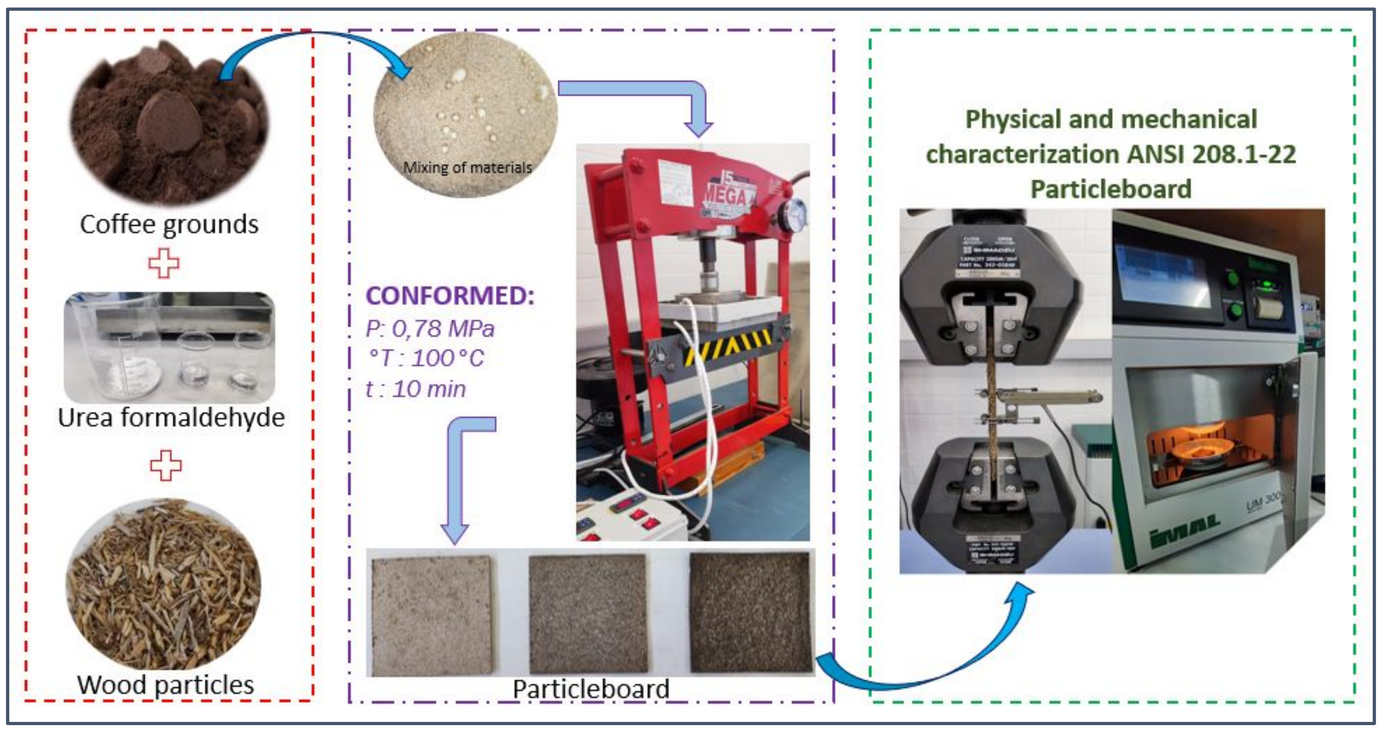

Figure 1. Processing of particleboard.

The characterization included the evaluation of dimensional tolerance, as well as the determination of physical and mechanical properties, covering aspects such as density, humidity, water absorption, thickness increase, MOE, MOR and internal adhesion; according to the **ANSI A208.1-22 Particleboard Standard** [8]. For this purpose, equipment such as: AG-X plus Universal Testing Machine, UM 3000 moisture meter, digital balance, micrometer and oven were used.

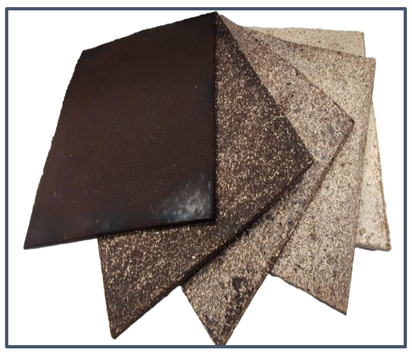

Figure 2. Particleboards with different concentrations of coffee grounds.

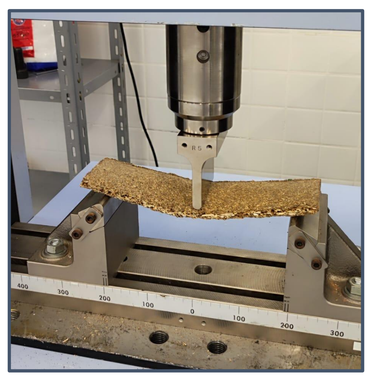

Figure 3. Flexure test of 50C-50W-15UF-3L-4C-6S specimen

RESULTS AND DISCUSSION

An improvement in the mechanical behavior of the boards with 15% adhesive has been evidenced, so multilayer boards are manufactured with this proportion of resin. Of the different compositions analyzed, the board with 25% coffee grounds and a distribution of particulate material: 40% in the core and 60% on surfaces, reflects an increase in flexural strength. On the other hand, with a 50% coffee grounds concentration, the best performance arises if the particulate material is mainly concentrated in the core.

Particleboards of coffee grounds are classified as low density boards because they have a density of less than **0,640 g/cm³**, according to **ANSI A208.1-22 Particleboard**. The dimensional thickness tolerances, as well as the physical and mechanical characteristics indicated in the standard, are not met due to the use of a heated press that does not reach pressures and temperatures higher than 2.5 MPa and 160°C, respectively, as pointed out by authors who manufacture boards with other types of biowaste [9-11].

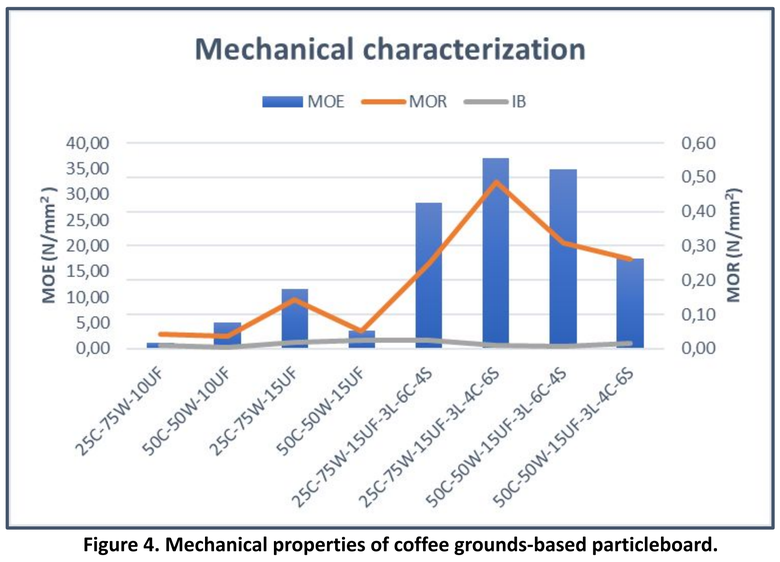

Figure 4. Mechanical properties of coffee grounds-based particleboard.

Table 2. Physical and mechanical properties of particleboards of coffee grounds .

Standard	Particleboard	Density	Length and width	Average thickness variation		MOE	MOR	IB	Moisture	Water absorption	Thickness increase 24 h
				MAX	MIN						
ANSI A208.1 Particleboard	25C-75W-10UF	0,468	± 0	0,524	-0,314	1,24	0,04	0,0088	12,47	154,89	48,10
	50C-50W-10UF	0,408	± 0	0,602	-1,008	5,21	0,04	0,0039	11,95	173,55	35,20
	25C-75W-15UF	0,535	± 0	0,488	-0,452	11,65	0,14	0,0181	12,23	109,35	28,66
	50C-50W-15UF	0,635	± 0	0,470	-0,300	3,44	0,05	0,0235	12,25	89,03	40,22
	25C-75W-15UF-3L-6C-4S	0,468	± 0	0,514	-0,564	28,39	0,25	0,0244	12,03	132,01	36,59
	25C-75W-15UF-3L-4C-6S	0,451	± 0	0,798	-0,656	37,05	0,49	0,0112	12,02	145,53	41,33
	50C-50W-15UF-3L-6C-4S	0,524	± 0	0,758	-0,472	34,81	0,31	0,0066	12,25	90,82	33,24
	50C-50W-15UF-3L-4C-6S	0,566	± 0	0,594	-0,729	17,55	0,26	0,0153	11,26	95,80	39,89
	LD-1	*< 0,640*	*±2,0*	*0,125*	*-0,375*	*500*	*2,80*	*0,10*	< 10%	-	-
	LD-2							*0,14*			

CONCLUSIONS

The use of coffee grounds as a substitute material for the manufacture of chipboard shows a high potential, with the capacity to reach a maximum concentration of 50%. In addition, coffee grounds have a uniform particle size, which would avoid associated grinding costs, reduce the demand for wood as a raw material and avoid environmental pollution resulting from the biodegradation of the waste. In short, the research carried out highlights the need to optimise the manufacturing process in order to obtain a product that meets the required standards.

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