Environmental friendly plastic tiles for substituting wooden board, and its processing machine design

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Abstract. Plastic waste has become a global problem because it cannot be degraded in nature and in its manufacturing process requires non-renewable resources. For this reason, we need communal awareness to reduce, reuse and recycle plastic. Participating in this awareness, this paper intends to design plastic tiles made from plastic waste to replace natural wooden boards. Wooden boards are industrial forestry products that are becoming more and more expensive because of forestry wood materials are now increasingly scarce. Plastic used as raw material for the plastic tiles is recovered from the land fill. This study also worked on the design of equipment to process plastic waste into plastic tiles. This plastic hot press machine is made of a UNP steel frame. The top heating plate and bottom heating plate use CNC milled aluminum alloy equipped with 8×500 Watts cartridge heater. The heating plate temperature is set with the temperature controller. And the pneumatic piston of 80mm bore × 200mm stroke, 10 Bar, controlled by Outseal PLC. The plastic hot press machine produces two plastic tiles of 240mm×340mm×5mm size, weighing 387gr each, in 110 minutes. Tensile test according to ASTM D638 standard on product specimens shows tensile strength up to 18.0MPa.

Keywords: environmental-friendly, eco-friendly, green processes, plastic recycling, wood substitute.

1. Introducing of plastic waste problems
For the past two decades, the industry has seen the benefits that inclose the use of plastic. They conceive the challenges of the opportunities and priorities of using plastic as a future material. Throughout the increasing use of plastics, ecological issues and health impacts also emerged[1][2]. The emerging issue of ecology and health impacts has exert the waste management issue and environmental protection[3][4] and encouraged community awareness to care about reduce, reuse, recycle of plastic[5][6]. There have been many work by researchers to reduce the use of plastic polymers. Kershaw [7] has explored and adopted alternative plastic replacement materials using natural polymer bases. Pringle and Barker [8] and Wong [9] in their work conducted a study of plastic recycling business startup and plastic recycling supply chain. The technology of recycling intermix plastic compound of more than one type of plastic has been introduced by Hegberg et.al. [10]. Cui et.al. also introduced environmentally friendly plywood using recycled plastic films bonding[3].
2. The prior works
Cui et.al [3] Song et.al [11] Bekhta and Sedliacik [12] carried out the development of environmentally friendly plywood due to the insistence of the plywood industry known for its highly toxic formaldehyde emissions[13][14]. Many researchers also combine plastic waste and cellulose materials obtained from wood waste, wheat or rice husks, or paper waste[15] [16] [17] [18]. Tong.et.al[15] conducted a study of the mechanical properties and morphology of HDPE composites using rice husk fillers while Pelita.et.al[19] conducted a similar study on PP and cocofiber composites. Several plastic-cellulose composite techniques are applied, including laminate composites [16][12], matrix fiber composites [17][20][21], matrix flake composites[15][18][22]. Even though wood-plastic composites can reduce of plastic waste mass in land fills, improve the physical mechanical properties of wood, it also creates new problems in its life-cycle when plastic-wood composite products are disposed of. It increases the volume of plastic waste by including the volume of wood in it [13].

Another approach by researchers in plastic recycling is to treat plastic waste as a substitute for building wood material [6][23] using the thermoforming compression molding[24]. This approach was also applied by Sabarudin.et.al.[25] by developing portable hot press machines to process plastic waste for wood substitutes.

3. Design concept, functional requirements and methods
The portable hot press machine has been designed to process waste plastic flakes into plastic slabs for plywood substitution. Machine process parameters can be controlled easily. Equipped with a controller that easily adjusts temperature, heating time, and applied thermoforming pressure. This plastic slab processing machine is intended for micro small and medium industries with a maximum footprint space of 80 cm × 120 cm and the electrical power requirements under 4kW. To simplify maintenance and reduce maintenance costs, the machine has been designed with a modular unit that is easily reconfigured and developed for future thermoforming needs.

![Figure 1. Virtual prototyping of portable hot press. (a) main frame, (b) control box, (c) upper heating plate, (d) lower heating plate, (e) full assembly.](image-url)
The machine design starts from the process selection to make a plastic slab. Flake plastic waste treatment utilizes the thermoforming process. The plastic flake preform is placed in the mold cavity, then high pressure and high temperature are applied so that the preform melts and fills the shape of the mold cavity. To accommodate the thermoforming process, the main frame parts, bottom heater molds, upper heater molds, pneumatic drive and control box were built.

The virtual prototype design of portable hot press machine was built using Inventor (fig 1). This process bring down the design concept to a virtual prototype. The virtual prototype is tested for the conformity of the geometric dimensions of components fabricated with the geometric dimensions of the standard components purchased, including pneumatic piston, cartridge heater, solenoid valve, temperature controller. Virtual prototypes also test functional designs to run properly.

![Experiment setup for plastic slab characterization. (a) portable hot press machine, (b) tensile test machine, (c) tensile test specimen, (d) temperature process curve as function of time.](image-url)
4. Final design and product characteristics

The final design of a portable hot press machine (fig 2. a) consists of main frame components fabricated using UNP10 mild steel. This main frame (fig 1. a) serves as the supporting structure for the bottom heater mold (fig 1. d), pneumatic piston, control box (fig 1. b) and other supporting components. Pneumatic piston uses 80mm bore diameter and 200mm stroke with 10Bar working pressure. The bottom heater molds (fig 1. d) and top heater molds (fig 1. c) use a CNC milled aluminum alloy inserted with 8 cartridge heater 500Watts each. The temperature and applied pressure of the thermoforming process are controlled by the temperature controller and Arduino Outseal PLC respectively.
Typical temperature curve for the thermofroming heating process is shown in fig 2. (d) with the heater temperature set at 200°C and holding time for 3 minutes. This portable hot press machine produces a 240mm × 340mm square, 5mm thick plastic slab with an average electric energy consumption of 0.43 kWh. Tensile test results using the ASTM D638 test standard with Zwick Z020 tensile test equipment provide a Tensile strength of 18.0MPa, with elongation of 11.8% and elastic modulus of 289.9MPa.

5. Conclusion and future work
The results of the test characteristics of the portable hot press machine have achieved the expected results. The hot press machine can run the thermoforming process to produce recycled plastic slabs for the substitution of 5mm plywood material. Making plastic slabs requires electrical energy of 0.43kWh on average to make 387gr plastic slabs. The shortcoming that must be addressed from the current design is that the cooling time of the mold takes up to 40 minutes to be able to disassemble the mold. The next improvement is to separate the heating plate with molds so that molds replacement can be done without having to turn off the heating plate.

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