Design and performance of a manual extruder for recycled plastic-brick composite pavers

Abdelkader Daikh[a], *Youcef* Moulai Arbi[b],
Mohammed Bentahar[c], *Noureddine* Mahmoudi[d]

[a] University of Mustapha Stambouli, Faculty of Technology,
Department of hydraulics,
Mascara, People's Democratic Republic of Algeria,
e-mail: daikhaek@gmail.com,
ORCID ID: https://orcid.org/0009-0006-4090-4516

[b] University of Mustapha Stambouli, Laboratory of Quantum Physics of Matter and Mathematical Modeling (LPQ3M),
Mascara, People's Democratic Republic of Algeria,
e-mail: youcef.moulaiarbi@univ-mascara.dz, **corresponding author**,
ORCID ID: https://orcid.org/0000-0002-6534-8820

[c] Universiy of Saida Dr. Moulay Tahar, Faculty of Technology,
Department of Civil Engineering and Hydraulics,
Saida, People's Democratic Republic of Algeria,
e-mail: bentahae@yahoo.fr,
ORCID ID: https://orcid.org/0000-0002-2166-678X

[d] Universiy of Saida Dr. Moulay Tahar, Faculty of Technology,
Department of Civil Engineering and Hydraulics,
Saida, People's Democratic Republic of Algeria,
e-mail: mahmoudi.noureddine@yahoo.fr,
ORCID ID: https://orcid.org/0000-0002-9740-0857

doi https://doi.org/10.5937/vojtehg72-52422

FIELD: mechanical engineering, civil engineering
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: This study aimed to develop a cost-effective manual plastic brick extruder for manufacturing composite bricks from recycled polypropylene and brick powder. The goal was to address housing challenges in developing countries while promoting sustainable waste management.

Methods: A single screw extruder with a 60 mm die was fabricated, featuring a manual crank, a heating system, and a hopper. Composite specimens with varying polypropylene (30-80 weight percentages) and brick powder (20-70 weight percentages) ratios were produced. Mechanical testing was conducted, including compressive strength, flexural strength, impact resistance, and density measurements.

Results: The 40:60 polypropylene:brick powder mixture exhibited optimal compressive strength, ranging from 23.76-24.90 MPa. Flexural strength *peaked at the 50:50 ratio (11.86-12.5 MPa). Impact resistance decreased with increasing brick powder content. Density increased linearly with brick powder content, ranging from 1.48-1.77 g/cm³. The extruder successfully produced uniform composite specimens across all mixtures.*

Conclusions: The study demonstrated the feasibility of producing composite bricks using a low-cost, manually operated extruder. Two optimal mixture compositions were identified: 40:60 polypropylene:brick powder for maximum compressive strength and 50:50 for optimal flexural strength. This approach offers a promising solution for affordable housing construction while addressing plastic waste management in developing regions. Future research should focus on optimizing the extrusion process, exploring additional waste materials, and conducting long-term durability studies of composite bricks.

Key words: manual extruder, polypropylene, brick powder, composite, pavers.

Introduction

Composite materials, integral to modern materials science and engineering, combine distinct phases to achieve superior properties. Comprising a matrix and reinforcing elements, these materials offer tailored characteristics that surpass individual components.

The synthesis of polymer-ceramic composites represents a significant frontier in materials science, combining the flexibility and low density of polymers with the high strength, hardness, and thermal stability of ceramics. The melting method emerges as a key technique in this field, wherein the polymer matrix is transformed into a molten state to facilitate the integration of ceramic reinforcements. This approach allows for the creation of materials that synergistically blend the advantageous properties of both constituents (Ali et al, 2023). The meticulous control of temperature during the melting phase ensures the homogenous dispersion of ceramic particles within the molten polymer. Subsequent cooling solidifies the composite, leading to a final material with a synergistic blend of properties. The melting method offers precision in tailoring the composite's microstructure, resulting in enhanced mechanical, thermal, and functional characteristics.

Polymer-ceramic composites, produced via cost-effective methods like melting, offer an innovative solution for plastic brick manufacturing in developing countries. These composites combine polymer flexibility with ceramic strength, creating affordable, durable bricks ideal for refugee housing or earthquake-prone areas (Moulai Arbi, 2024). This approach offers dual benefits: providing affordable construction materials and reducing waste through plastic recycling. It presents a sustainable solution for resource-constrained regions while advancing eco-friendly, economical building materials globally. (Thatheyus et al, 2020)

In their study, Patil et al. (2020) conducted an experimental study on manufacturing plastic sand bricks using waste polypropylene (PP) and polyethylene (PET). They processed post-consumer plastic waste, melting PP and PET at 160°C and 180°C, respectively, and mixed them with sand in ratios from 1:2 to 2:5. Six brick samples were produced and tested according to standard methods. Notably, the brick with a 2:1 plastic-to-sand ratio achieved a compressive strength of 12.43 N/mm², exceeding that of traditional clay bricks. The samples also exhibited excellent durability, with zero efflorescence and low water absorption rates (0-2.82%). This study demonstrates the potential of converting plastic waste into high-quality construction materials.

Moulai Arbi et al. (2023) investigated the enhancement of thermal and mechanical properties of waste polyethylene terephthalate (PET) composites by incorporating brick sand reinforcement. The study evaluated the effects of varying sand filler content (30% to 45%) on the degradation temperature, glass transition, crystallization temperatures, tensile strength, Young's modulus, and Charpy impact strength. The addition of 45 wt% sand significantly improved the thermal degradation temperature from 220°C in neat PET to over 314°C. Optimal tensile strength (26.26 MPa) and Young's modulus (2771 MPa) were achieved at 30 wt% sand, but further increases in the filler content led to a decrease in Charpy impact strength due to poor interfacial adhesion.

Hamzah & Alkhafaj (2022) developed an innovative method for producing lightweight, eco-friendly bricks using low-density polyethylene (LDPE) plastic waste, such as medical syringes, combined with natural fillers like sawdust and sand. The study evaluated the mechanical and physical properties of these bricks. Bricks with 20% sawdust filler showed superior compressive strength (66 MPa) compared to those with higher sand content (61 MPa at 60% filler). Sand-filled bricks had low water absorption rates (under 1%), while sawdust variants absorbed up to 21%. The bricks' density varied, with 0.7 g/cm³ for 50% sawdust, and hardness peaked at 70D with 60% sand content.

Lamba et al. (2022) reviewed researchers using the hand rod mixing method to create plastic brick composites. This artisanal technique involves manually blending polymer and ceramic materials, highlighting a handcrafted approach, but it has significant scalability limitations. The hand rod mixing method, though meticulous, is inefficient for large-scale plastic brick production. Its manual nature limits rapid manufacturing and consistent quality, making it impractical for mass production despite its craftsmanship appeal.

Plastic extruders provide an efficient, automated solution for producing uniform filaments from recycled plastic, enhancing sustainability in material repurposing (Abeykoon et al, 2016).

Qin et al. (2024) analyzed extruder screw design and plastic wire diameter control, emphasizing the importance of die design and heater temperature for optimal efficiency. The study also highlighted extrusion technology's adaptability in recycling thermoplastic materials.

Hanifah et al. (2023) examined the impact of screw-barrel clearance and cooling fans on non-wheat noodle extruders. They found that reducing clearance and using cooling fans improved the extruder performance by preventing backflow, maintaining temperature, and enhancing the noodle quality and energy efficiency.

Reichel & Krause (2016) investigated waste heat during the extrusion of tubular profiles, focusing on energy efficiency and heat reuse. Their study identified opportunities for utilizing waste heat in single grooved barrel extruders. However, current extruder applications are mainly limited to thin plastic filaments for testing or 3D printing, with challenges in processing thicker materials, limiting broader industrial use.

Plastic extruders face limitations in producing polymer-ceramic composites due to their thin exit holes, hindering large-scale manufacturing of composite bricks. To address this, a dedicated plastic brick extruder has been proposed, designed to handle the unique requirements of polymer-ceramic composites. This specialized extruder, available in both manual and automated versions, aims to overcome the exit hole constraint and facilitate the production of larger structures. It features a large spiral screw and a dual-mode turning mechanism for enhanced efficiency and cost-effectiveness, particularly suited for developing countries. This innovation promises to advance composite material production and offer sustainable solutions for housing and infrastructure challenges.

Plastic brick extruder

The fabricated extruder is a single screw extruder. Single screw extruders are extruders which have only one screw in the system. They are commonly used for simple and general materials. In recent years, a lot of research has been done for more constant and stable extrusion. In extruders, a material is mixed inside the barrel until the length of the extrusion machine.

Extruders typically consist of mechanical parts and electrical parts.

Mechanical parts

Manual crank

The crank handle, an essential component of manual extruders, serves as a manual actuation mechanism for rotating the extruder screw within the barrel. This hand-operated device is characterized by its ergonomic design, facilitating the user's application of rotational force to the screw (Figure 1a)). Integral to its functionality is the presence of a notch (Figure 1b)) strategically positioned along its circumference. This notch serves a pivotal role by engaging with a complementary feature on the screw shaft, ensuring precise alignment and secure attachment. Through this engagement, the crank handle effectively translates the rotational motion exerted by the user into the corresponding movement of the extruder screw, thereby facilitating the controlled extrusion process essential for plastic processing applications.

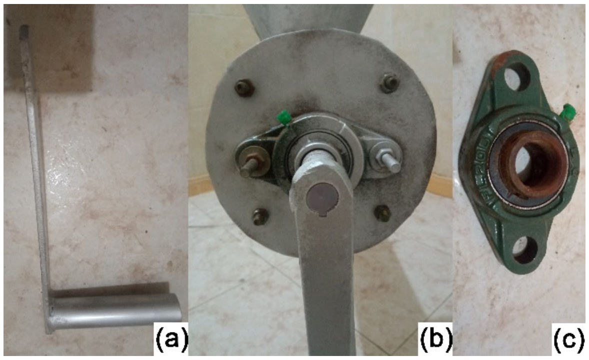

Figure 1 – (a) Crank handle, (b) notch for the crank handle, (c) Self-aligning bearing housings

The self-aligning bearing housings are pivotal components within manual extruder assemblies, instrumental in securing and positioning the extruder screw within the barrel (Figure 1c)). Crafted from durable cast iron, these housings provide robust support to the screw shaft, effectively enduring the mechanical stresses inherent to extrusion operations. Their inherent self-aligning capability enables them to adapt to minor misalignments, thereby enhancing operational efficiency and prolonging the extruder's lifespan. By ensuring the secure and precise fixation of the screw shaft, these bearing housings play a vital role in facilitating consistent and accurate plastic extrusion, meeting stringent quality requirements across diverse industrial applications.

Hopper

The hopper in Figure 2 serves as a pivotal component in the plastic extrusion process, acting as the entry point for raw materials into the extruder barrel. Typically situated atop the extruder assembly, the hopper provides a reservoir for the plastic pellets or granules, ensuring a continuous supply of material for the extrusion process. Its design often incorporates features to facilitate efficient material feeding, such as a wide opening for easy loading and a sloped interior to promote material flow towards the extruder screw.

The larger diameter opening at the top of the hopper, where materials are loaded, is a "filling port." In addition, it has a diameter of 20 mm. The smaller diameter opening, situated at the bottom of the hopper and connecting to the extruder barrel, is a "feeding inlet" and its diameter is 10 mm.

Figure 2 – Hopper

The feet of the extruder, integral to its stability and support, are constructed from stainless steel. These feet are engineered to withstand the mechanical forces exerted during extrusion operations while ensuring the extruder remains securely anchored to the operating surface. Additionally, the incorporation of small holes within these feet enhances their functionality by providing convenient attachment points for securing the extruder to auxiliary surfaces, such as wooden platforms or workbenches. Through these strategically positioned holes, users can employ screws or bolts to firmly affix the extruder, thereby optimizing its operational stability and minimizing the risk of movement or displacement during use.

Screw

Fabrication of a screw involves precise and methodical processes to ensure optimal performance and durability. The initial step in fabrication is the cutting and shaping of the screw flights as seen in Figure 3, which are typically made from flat metal sheets of stainless steel. These sheets are cut into the desired flight shapes, then formed into helical structures using metal forming tools. Once shaped, the flights are meticulously welded onto a central shaft, ensuring strong and smooth welds to prevent material buildup and ensure structural integrity.

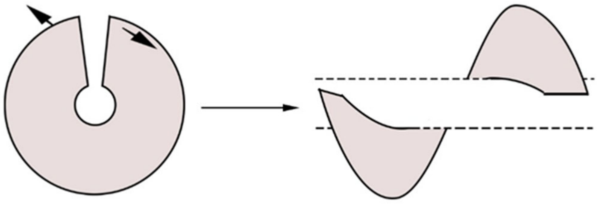

Figure 3 – Screw fabrication method

The screw conveyor under consideration features a pitch of 140 mm, a critical dimension influencing the material flow rate and conveying efficiency (Figure 4). The screw has a unique design, with a small diameter of 50 mm and a larger diameter of 160 mm, indicating a tapered or variable diameter design that can accommodate varying material characteristics and flow requirements. This design ensures efficient handling of materials by gradually increasing the conveyor's capacity along its length, thereby optimizing the load distribution and reducing the risk of blockages. The total length of the screw conveyor is 1000 mm, providing a substantial conveying distance suitable for various industrial applications. The combination of these dimensions—specifically, the 140 mm pitch with a tapered screw design—facilitates smooth and efficient material transport.

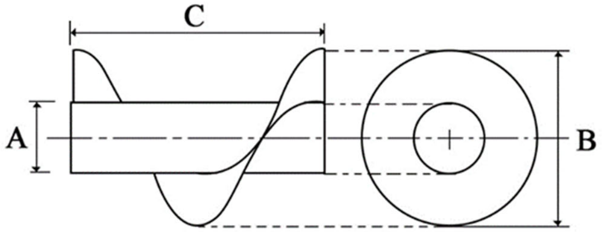

Figure 4 – screw conveyor dimensions

A= 50 mm
B= 160 mm
C= 140 mm

Figure 5 shows the manufactured screw. Typical plastic extruder screws have three zones of heating (feed zone, compression zone, and metering zone); however, our work does not include these zones because it works with big quantity of plastic and brick and the temperature is uniform all over the tube in order to avoid difficulty in moving the mixture.

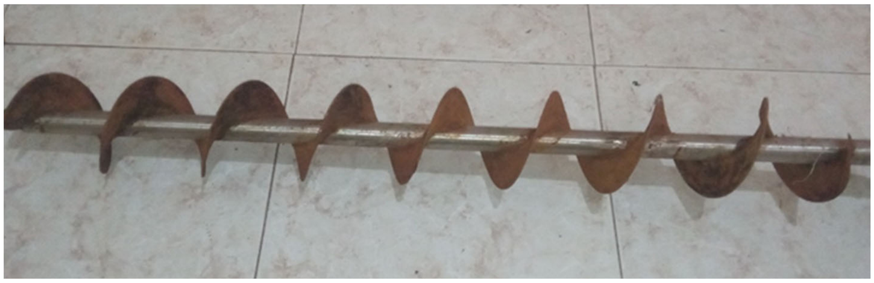

Figure 5 – Manufactured screw conveyor

Electrical parts

Electrical heaters are widely used nowadays because they are very efficient and cost reducing. They are not expensive to maintain in comparison to other heating systems.

A certain amount of current passes through the conductor with a certain resistance which works as a barrier in the flow and generate heat. The heat thus obtained is given below in the equation of Joule's Law:

$$Q = I^2Rt = V/t = V^2/Rt \qquad (1)$$

where:

Q=charge flow, R = resistance , I= current, V= voltage, and t= time .

Resistors as shown in Figure 6 are connected in parallel; they are subjected to the same voltage. Each resistor will have the same voltage across it, resulting in the same current flowing through each one. This ensures that they all generate the same amount of heat and thus maintain the same temperature.

Heating bands

The heating bands are manually fabricated by forming a cylindrical shape using ceramic paste (Figure 6a)), followed by creating four holes to allow electrical wires to pass through. Subsequently (Figure 6b)), the bands are cut in half to facilitate their installation in the extruder. The four heating bands in the extruder serve to prevent the transmission of electricity to the external body, ensuring safety.

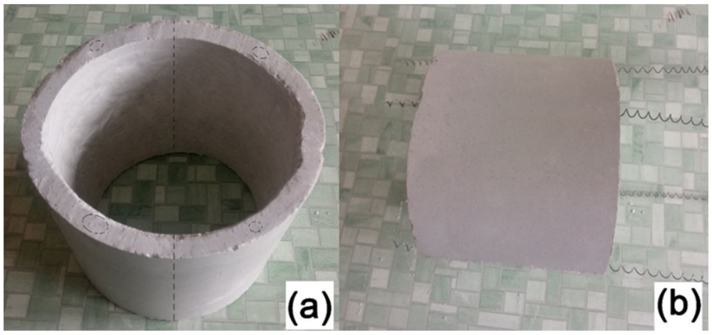

Figure 6 – (a) Heating bands, (b) Heating bands with resistance wires

PID controller

A PID (Proportional-Integral-Derivative) controller is a device which provides the Information to SSR (Solid State Relay) when to turn on and when to turn off. A PID reads the temperature of any system with the help of a thermostat. It functions as the input panel to the system (Figure 7a)).

General-purpose temperature controllers are used to control most typical processes in industry. Typically, they come in a range of DIN sizes and have multiple outputs and programmable output functions. These controllers can also perform PID control for excellent general control situations. They are traditionally placed in the front panel with the display for easy operator accessibility. These controllers have a pre-tune function to initially calculate the PID temperature for a process, and a continuous tune function to constantly refine the PID temperature. This allows for quick setup, saving time and reducing waste.

A sensor which is used to measure the temperature is known as a thermocouple. It consists of two wires made of different metals. When the two materials are subjected to the heat, it produces some electric voltage, which determines the reading of the temperature in the system. Thermocouples are used for their low cost, durability, and a high temperature range.

Thermocouple

The thermocouple (Figure 7b)), was connected to the input port. This port was the place where the heat sensor was connected. It was able to read temperature of the tube after connecting.

This enabled switching the heater on and off after obtaining required temperature. The power supply for the heater was also supplied thus completing the electrical wiring of the heat control mechanism.

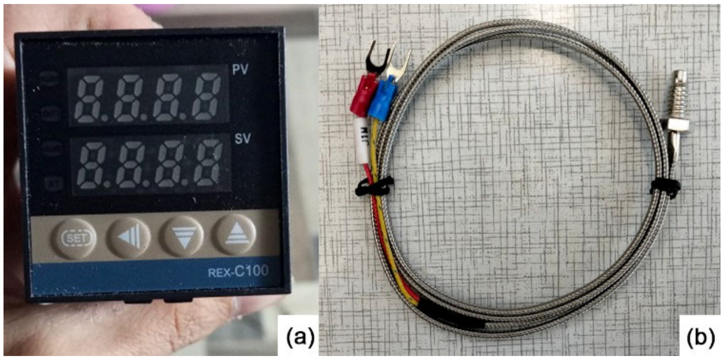

Figure 7 – (a) PID controler, (b) Thermocouple

Full body

Figure 8 illustrates the complete structure of the extruder, highlighting its essential components for its operation. The extruder features a tubular trough with a total length of 1400 mm, providing an extended path for the material to be processed. At the end of the trough, there is an exit hole, also known as the nozzle, which has a diameter of 60 mm. This exit hole is crucial for shaping the extruded material as it exits the conveyor. Additionally, the extruder includes a cylinder that encapsulates the resistance section, designed to maintain the necessary temperature for efficient extrusion. This cylinder, often referred to as a heating barrel, ensures that the material within the extruder remains at a consistent and optimal temperature, preventing cooling and solidification before it reaches the exit hole.

Figure 8 – Manuel plastic brick extruder

Preparation of plastic bricks

After the assembly of the extruder parts was completed, the machine was left 30 min with turning on the heat of 160 C°. After acquiring the stable temperature, the crank handle was turned on. The pellets and brick powder were then poured into the hopper. The handle turns at a speed of 5 rpm.

The composite was driven by the screw along the barrel. When the composite reached the heating section, it started melting and the pressure was created inside the tube. Due to heating from the heater, the temperature rises and completely melts the plastic. The paste was extruded through the die hole with a diameter of 60 mm.

Sand brick

Brick waste was collected from a brick factory. As shown in Figure 9, brick waste passed through a crushing process in order to obtain brick powder. The sieve pass used is 80µm. The brick powder was analyzed in the LAFARGE Company.

Figure 9 – Crushing presses for brick powder

Table 1 lists the chemical compositions and the physical characteristics of brick powder.

X ray diffraction analysis (XRD) is a technique used to analyze the crystalline structure of materials, while X-ray Fluorescence (XRF), is a technique used to determine the elemental composition of materials. The utilized machines are the Bruker S8 for XRF and the Bruker D4 for XRD.

The results show that the sum of the components [Al_2O_3 + Fe_2O_3 + SiO_2] for brick powder is 83.37%, which meets the requirements of ASTM C618. PAF (Particulate Airborne Fraction) is a column that contains a value representing the particulate airborne fraction, which is often a measure of the proportion of airborne particles emitted during a particular process or activity. It is reported as 0.74 (R_wp) and contains a value representing the weighted profile R-factor, which is a measure of the agreement between the observed and calculated X-ray diffraction patterns.

Table 1 – Properties of brick powder

Chemical composition (%)										
Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Loss	PAF
Quantity (%)	62.45	14	6.92	8.54	2	2.07	0.22	0.59	3.21	0.74
Mineral phases (W %)										
R_wp	calcite	dolomite	quartz	illite	kaolinite	chlorite	albite	microline	diaspore	topaz
7.54	0.95	3.97	47.48	17.17	0.75	0.43	11.81	13.71	0.27	3.96
Physical characteristics										
Density (g/cm^3)	2.43									
Blaine-specific surface (cm^2/g)	3140									

Polypropylene

PP is a strong lightweight plastic from the polymer family, known as a nonbiodegradable thermoplastic with a strong moisture barrier. PP, like all thermoplastics, becomes liquid at its melting point (160°C) and can be cooled without significant degradation of its properties. The excellent properties of PP made it commonly used in everyday items.

PP is used in this work as a matrix. PP waste was collected and cleaned with tap water to remove all forms of contaminants and harmful materials before sun drying for at least 3 days. The dried waste was then ground and pulverized into pellets ranging in size from 1 mm to 8 mm. Figure 10 shows the ground material.

Figure 10 – Polypropylene particles.

Preparation of test specimens

PP and brick powder were dried at 50° in the oven and then passed into the fabricated plastic brick extruder at a temperature of 160°. After that, the melted mixture was recovered at the outlet and then put into molds. The utilized molds are for mechanical tests, compressive strength, flexural strength, Charpy test and cylindrical compressive test. The molds were oiled in order to facilitate specimen’s removal.

The dimensions of the compressive strength specimens are cubic: 50mmX50mmX50mm in accordance with ASTM C109 (ASTM, 2020).

The dimensions of the flexural strength specimens are prismatic: 40mmX40mmX160mm in accordance with ASTM C78 (ASTM, 2022).

The dimensions of the Charpy test specimens are prismatic with a V notch of angle 45° in the middle: 40mmX40mmX160mm in accordance with ASTM D6110 (ASTM, 2018).

The dimensions of the cylindrical test specimens are 160mmX320mm (diameter x height) in accordance with ASTM C39 (ASTM, 2023).

Figure 11 displays the prismatic specimens with varying weight percentages of polypropylene (PP) in the mixture, ranging from 30 w% to 80 w%. The specimens with less than 30 w% PP could not form correctly because the low PP content was insufficient to properly bind the reinforcement. Conversely, the specimens with more than 80 w% PP exhibited poor distribution of brick powder, leading to clusters of PP and brick powder that made the specimens prone to cracking. Consequently, these specimens were excluded from the testing.

Figure 11 – Plastic brick specimens (prismatic).

Table 2 presents the mixtures with different PP W% and brick powder W%. Six samples were obtained for every mixture. Only for the cylindrical test specimens there were three samples. The mixture utilized for the cylindrical test specimen is based on the high results of the compressive strength test.

Table 2 – Mixtures with different weight percentages

Mixtures n°	M_1	M_2	M_3	M_4	M_5	M_6
PP weight%	80	70	60	50	40	30
Brick powder weight%	20	30	40	50	60	70

Mechanical tests

Mechanical tests were conducted on the specimens to investigate their performance under various conditions.

Bending test

Figure 12 presents the utilization of the three-point bending methodology employing an ELE International machine where the maximum applied load is quantified in kilonewtons (kN). This approach determines flexural strength by dividing the maximum load by the specimen's cross-sectional area, yielding a measurement expressed in newton’s per square millimeter (N/mm²), commonly referred to as megapascals (MPa). Prismatic specimens are subjected to bending forces, necessitating pre- and post-testing observations to discern any structural alterations. This experimental procedure offers indispensable insights into a material's capacity to endure bending stresses, furnishing invaluable empirical evidence for engineering and material science inquiries.

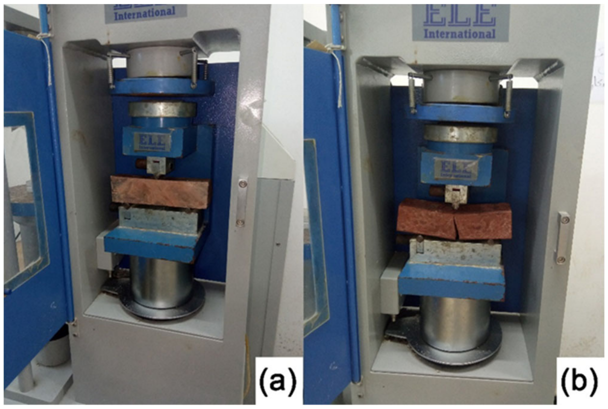

Figure 12 – Three-point bending test (a) before the test, (b) after the test

Compressive strength test

Figure 13 illustrates the compression testing process before (fFgure 13a)) and after the test (Figure 13b)), conducted utilizing an ELE International machine, with the cubic specimens employed for evaluation. The compressive strength of the material is assessed through this method. Similarly to the bending test, the specimens undergo observation both before and after compression to identify any structural changes. This experimental approach, facilitated by the ELE International apparatus, provides crucial insights into the material's ability to withstand compressive forces by comparing the conditions of the specimens before and after the testing.

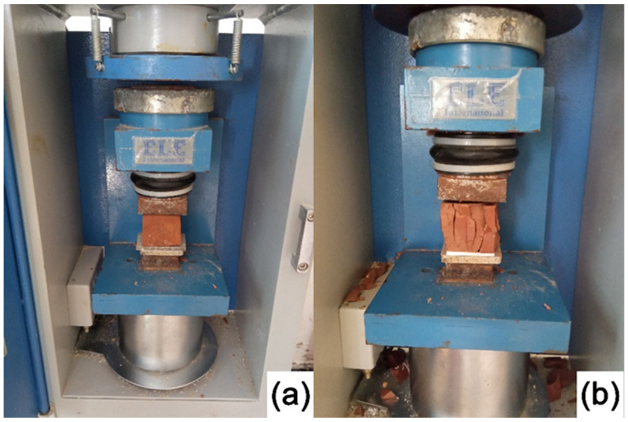

Figure 13 – Compressive test, (a) before the test, (b) after the test

Charpy test

Figure 14 displays the prismatic specimen featuring a notch (Figure 14a) , 14b)), alongside the JB-300B machine utilized for Charpy impact testing (Figure 14c)). This test, conducted to assess a material's resistance to sudden impact, yields results in terms of impact energy, measured in joules (J). The specimen is subjected to a swinging pendulum, which strikes the notched area, causing fracture. The amount of energy absorbed by the specimen before fracture provides crucial information about its toughness and resilience.

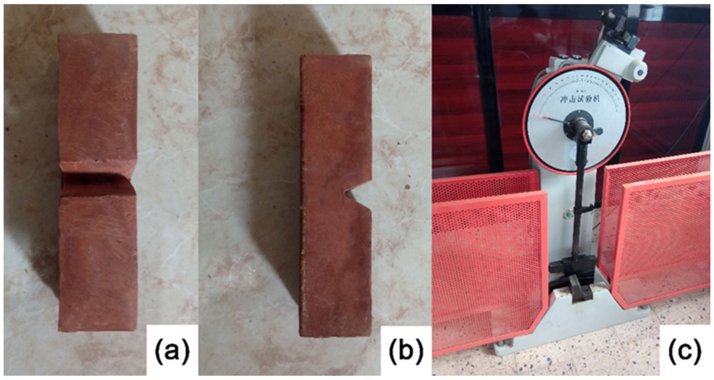

Figure 14 – Charpy test, (a,b) notched specimen, (c) test machine

Compressive strength (160X320 cylinder)

Figure 15 presents the cylindrical specimen used for compressive strength testing (Figure 15a)), alongside the RP 3000 XP machine employed for the procedure (Figure 15b)). This test, conducted on a 160x320mm cylindrical specimen, aims to determine the material's compressive strength. The RP 3000 XP machine applies a gradually increasing load to the specimen until failure occurs, allowing for the measurement of the maximum compressive force endured by the material.

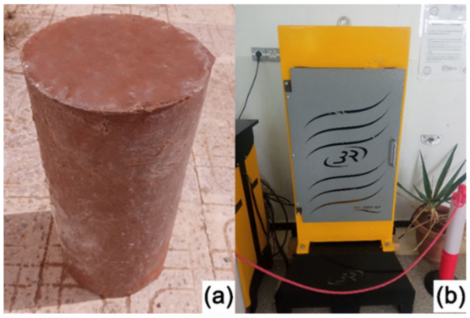

Figure 15 – Compression test of cylindrical specimens (a), using a test machine (b).

Density test

The cubic specimens were weighed using an electronic scale in Figure 16 to determine their mass in grams (g), then their volume in cubic centimeters (cm^3), which allowed us to use the equation below to determine their density.

$$\rho = \frac{m}{v} \tag{2}$$

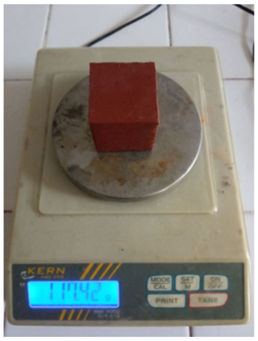

Figure 16 – Density test

Results and discussion

The experimental results obtained from the controlled tests bellow are designed to analyze the composite obtained from the production, and to understand the overall properties of the material.

Flexural strength results

Table 3 presents the results of the specimens subjected to the flexural test. The mixture M4 (composed of 50 w% polypropylene and 50 w% brick powder) demonstrated the highest resistance to bending, with the flexural strength values ranging from 11.86 MPa to 12.5 MPa across all samples. The mixture M5 showed slightly lower resistance, with the values between 11.21 MPa and 12.4 MPa. In contrast, the mixture M6 exhibited the lowest resistance to bending, with the flexural strength values ranging from 8.23 MPa to 9.32 MPa.

Table 3 – Flexural strength results

	Flexural strength (MPa)					
Mixtures n°	M_1	M_2	M_3	M_4	M_5	M_6
Sample 1	10.3	11.2	12.11	12.5	12.4	9.32
Sample 2	10.2	11.1	11.98	12.42	12.33	8.22
Sample 3	10.21	10.78	11.89	12.3	12.02	9.12
Sample 4	10.11	10.65	11.73	12.09	11.83	9.05
Sample 5	9.77	10.05	11.45	12	11.58	8.97
Sample 6	8.96	9.75	10.44	11.86	11.21	8.23

Figure 17 illustrates the effect of adding brick powder on the bending resistance of the specimens. The six samples demonstrated consistent behavior in response to the test, indicating a uniform mixture provided by the extruder during production. The results reveal an increase in flexural strength with the addition of brick powder from 20% to 50% by weight. This improvement is attributed to the enhanced bonding performance between the materials. However, a decrease in flexural strength is observed when the brick powder content is increased from 60% to 70% by weight. This decline is likely due to the inferior properties of ceramics under bending stress.

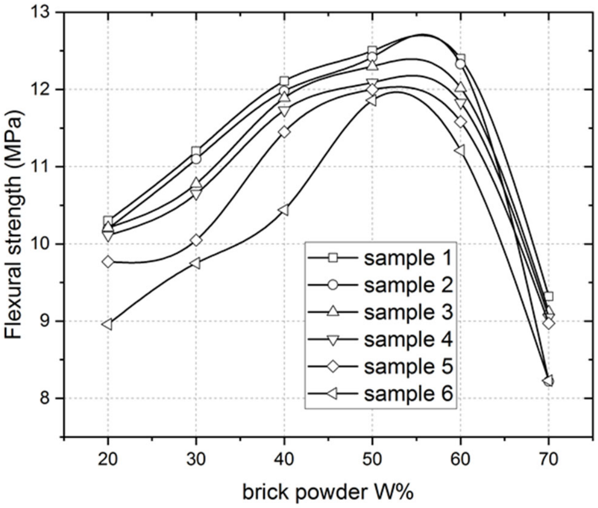

Figure 17 – Influence of brick powder percentage on flexural strength

Compressive strength results

The compressive strength results for various mixtures are presented in Table 4. The data shows the compressive strength values for six different samples of each mixture. The results indicate that the mixture M5 (PP 40w% , brick powder 60w%) exhibits the highest compressive strength, ranges from 23.76 MPa to 24.90 MPa, followed by the mixtures M4 (from 22.30 MPa to 23.44 MPa) and M3 (from 21.36 MPa to 22.50 MPa). The mixture M1 (from 19.18 MPa to 20.32 MPa) shows the lowest compressive strength.

The six samples show good agreement in terms of the observed increases and decreases in compressive strength in Figure 18, which is attributed to the small volume of the 50x50 mm cubes, providing precise results. The graph clearly shows that the mixture M5 (containing 40% polypropylene and 60% brick powder) exhibits the greatest compressive strength, due to the high performance of ceramics under compression. This is followed by the mixture M4 which shows slightly lower compressive strength. The mixtures M1 through M3 display a progressive increase in compressive strength, attributed to the addition of brick powder. The decrease in compressive strength from the mixture M5 to the mixture M6 is explained by the excessive amount of brick powder overwhelming the polymer matrix, leading to poor reinforcement distribution.

Table 4 – Compressive strength results

	Compressive strength (MPa)					
Mixtures n°	M_1	M_2	M_3	M_4	M_5	M_6
Sample 1	20.32	21.83	22.50	23.44	24.90	21.35
Sample 2	19.72	21.15	21.82	22.78	24.22	20.67
Sample 3	19.85	21.30	22.06	22.97	24.43	20.77
Sample 4	19.31	20.82	21.45	22.43	23.89	20.34
Sample 5	20.30	21.01	21.68	22.62	24.08	20.53
Sample 6	19.18	20.69	21.36	22.30	23.76	20.21

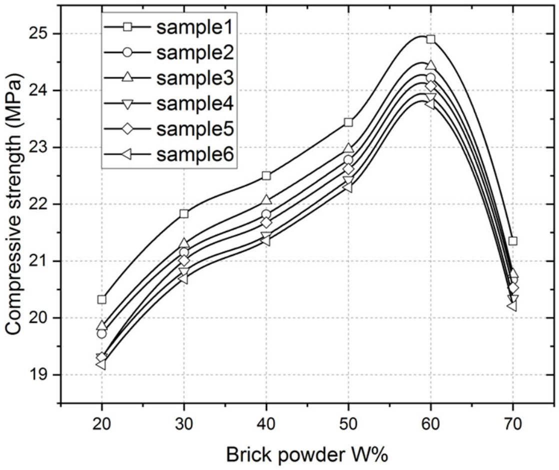

Figure 18 – Influence of brick powder on compressive strength

Charpy test results

Table 5 presents the Charpy test results, showing the impact energy absorbed by various mixtures. The mixture M1 demonstrated the highest impact energy, with the values ranging from 14.9 J to 20.92 J across all samples, indicating superior impact resistance. Conversely, all samples under the mixture M6 exhibited the lowest impact energy, ranging from 2.62 J to 6.71 J, suggesting poor impact resistance.

Table 5 – Charpy test results

	Impact energy (J)					
Mixtures n°	M_1	M_2	M_3	M_4	M_5	M_6
Sample 1	20.92	16.96	15.73	12.55	8.81	6.71
Sample 2	19.48	16.43	15.21	12.12	8.20	6.28
Sample 3	18.70	15.87	14.64	11.51	7.15	5.80
Sample 4	17.87	15.04	14.08	10.68	6.54	4.58
Sample 5	16.26	14.69	13.51	10.33	5.93	3.97
Sample 6	14.9	13.99	12.99	9.20	5.19	2.62

The graph in Figure 19 illustrates a progressive decline in brick powder content across six samples, ranging from an initial 20 w% to a concluding 70 w%. This reduction is attributed to the unfavorable characteristics of ceramics under mechanical shock. As more powder is incorporated, the polymeric matrix experiences diminished integrity, thereby compromising its ductility typical of polymers while augmenting the inherent fragility characteristic of ceramics.

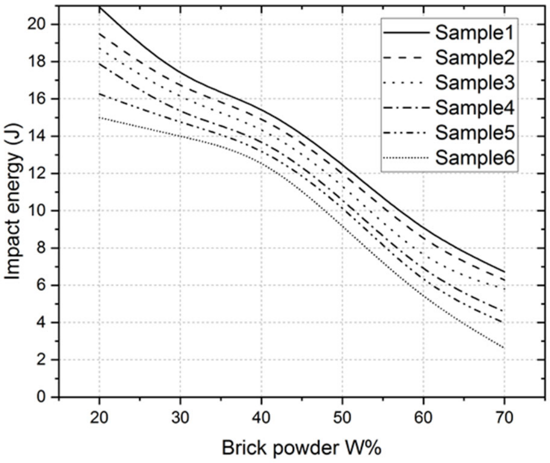

Figure 19 – Influence of brick powder on impact energy

Compressive strength (160mmX320mm) results

Table 6 presents the maximum compressive forces recorded from the cylindrical compression testing. Among the samples tested under the mixture M5, which was selected based on its superior performance in cubic compressive strength from Table 5, sample 3 achieved a peak compressive force of 34 kilonewtons (kN).

Table 6 – Compressive force results

	Max compressive force (KN)
Mixtures n°	M_5
Sample 1	32
Sample 2	32.5
Sample 3	34

Figure 20 presents a compressive force displacement graph.The three samples composed of 40 w% of (PP) and 60w% of brick powder exhibit a progressive rise in compressive force during displacement, until reaching their peak, followed by immediate failure. This pattern mirrors the ceramic material properties and provides a compelling indication that the samples under the mixture M5 adopt a more ceramic-like behavior.

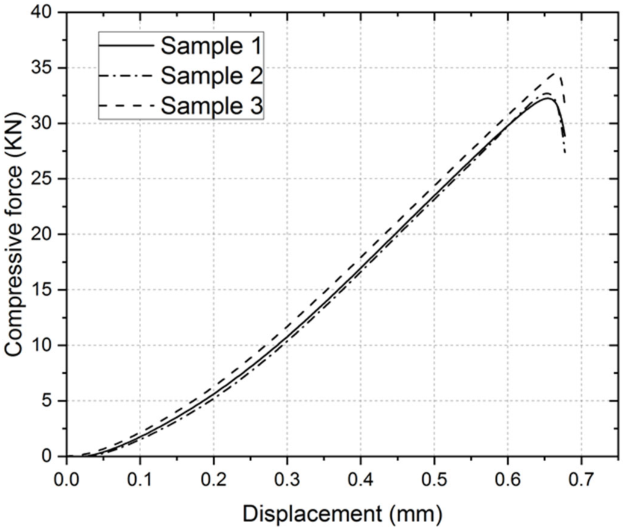

Figure 20 – Force displacement curve for plastic brick

Density test results

Table 7 displays the densities of six samples with varying mixtures. The mixture M1 exhibited the lowest density values, ranging from 1.48 g/cm³ to 1.56 g/cm³, while the mixture M6 demonstrated the highest density values, ranging from 1.68 g/cm³ to 1.77 g/cm³.

Table 7 – Density test results

	Density (g/cm^3)					
Mixtures n°	M_1	M_2	M_3	M_4	M_5	M_6
Sample 1	1.56	1.60	1.64	1.68	1.72	1.77
Sample 2	1.50	1.54	1.58	1.62	1.66	1.70
Sample 3	1.52	1.56	1.6	1.64	1.68	1.72
Sample 4	1.55	1.59	1.63	1.67	1.71	1.75
Sample 5	1.48	1.52	1.56	1.60	1.64	1.68
Sample 6	1.53	1.57	1.61	1.65	1.69	1.73

Figure 21 illustrates the density test results, revealing a trend of increasing density with higher brick powder content in the matrix (from 20 w% to 70 w%). This increase is attributed to the inherently dense properties of ceramics. As shown in Table 2, the density of brick powder is 2.43 g/cm³.

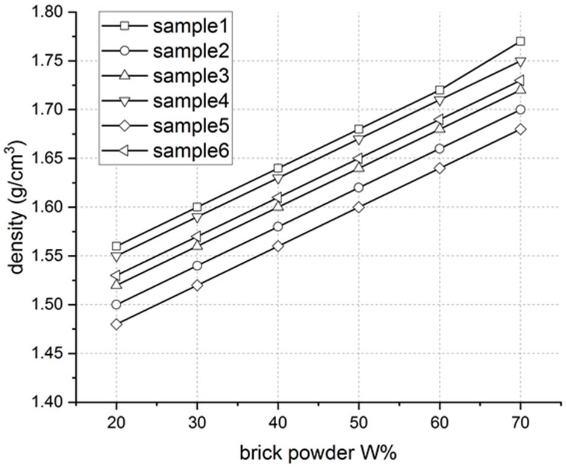

Figure 21 – Influence of brick powder on density

Paver blocks

Figure 22 illustrates the fabrication process of the desired product, which is pavers. The manual extruder enabled the large-scale production of the composite material. The mixture utilized for fabricating pavers is referred to as M5, consisting of 40% polypropylene (PP) and 60% brick powder by weight. This mixture is poured into a pre-oiled mold to facilitate the easy removal of the paver. After allowing the mixture to set for approximately 30 minutes, the paver is removed, resulting in the final product as depicted in the right-hand part of Figure 22.

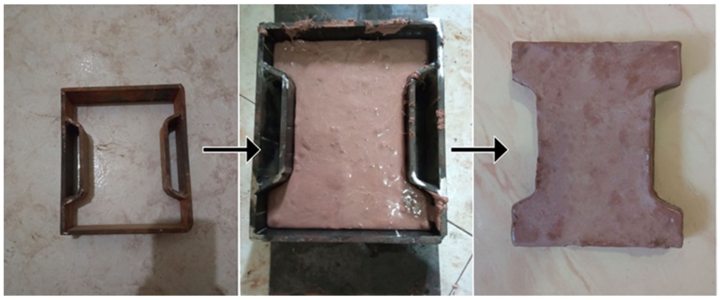

Figure 22 – Plastic brick paver manufacturing

Conclusion

This research successfully developed a cost-effective, manually operated plastic brick extruder for manufacturing composite bricks from recycled polypropylene (PP) and brick powder. The investigation demonstrated that the extrusion of plastic bricks is feasible with careful operation.

The feed mechanism allowed for constant-rate filament drawing, producing uniform mixtures across six samples. However, overloading the hopper led to premature melting and extrusion difficulties. Removal of melted composite from the pipe proved challenging, requiring either remelting or screw removal. Extended operation resulted in heat transfer to the extruder frame, indicating a need for improved thermal management in future designs.

The 60 mm die diameter facilitated easy extrusion, while the single-channel heating system proved sufficient for the melting process. This design successfully melted most polymers, showcasing its versatility.

Through extensive testing, two optimal mixture compositions were identified: a 40:60 PP:brick powder ratio for maximum compressive strength, and a 50:50 ratio for optimal flexural strength. These compositions effectively balance the ductility of the polymer with the strength of the ceramic component, making them suitable for various construction applications.

This study demonstrates the viability of producing composite bricks using a low-cost, manually operated extruder. The approach offers a promising solution for affordable housing construction while addressing plastic waste management. Future research should focus on optimizing the extrusion process, exploring additional waste materials as potential ingredients, and conducting long-term durability studies of composite bricks under various environmental conditions.

In conclusion, this research contributes significantly to sustainable construction practices and waste management strategies in developing countries. The developed extruder and composite brick formulations have the potential to reduce housing costs and environmental impact, paving the way for more accessible and sustainable building solutions in resource-constrained regions.

References

Abeykoon, C., Kelly, A.L., Brown, E.C. & Coates, P.D. 2016. The effect of materials, process settings and screw geometry on energy consumption and melt temperature in single screw extrusion. *Applied Energy*, 180, pp.880-894. Available at: https://doi.org/10.1016/j.apenergy.2016.07.014.

Ali, D.C., Jassim, A.K. & Al-Sabur, R. 2023. Recycling of Polyethylene and Polypropylene Waste to Produce Plastic Bricks. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 11(4), art.number: 1110462. Available at: https://doi.org/10.13044/j.sdewes.d11.0462.

-ASTM. 2018. ASTM D6110-18: Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics. *ASTM.org,* 09 May. Available at: https://doi.org/10.1520/D6110-18.

-ASTM. 2020. ASTM C109/C109M-20: Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). *ASTM.org,* 12 March. Available at: https://doi.org/10.1520/C0109_C0109M-20.

-ASTM. 2022. ASTM C78/C78M-22: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). *ASTM.org,* 30 March. Available at: https://doi.org/10.1520/C0078_C0078M-22.

-ASTM. 2023. ASTM C39/C39M-21: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. *ASTM.org,* 15 December. Available at: https://doi.org/10.1520/C0039_C0039M-21.

Hamzah, A.F. & Alkhafaj, R.M. 2022. An investigation of manufacturing technique and characterization of low-density polyethylene waste base bricks. *Materials Today: Proceedings*, 61(Part 3), pp.724-733. Available at: https://doi.org/10.1016/j.matpr.2021.08.318.

Hanifah, U., Taufan, A. & Sholichah, E. 2023. Effect of The Screw-Barrel Clearance and The Cooling Fan on Non-Wheat Noodle Extruder Performance. *BIO Web of Conferences*, 69, art.number:03017. Available at: https://doi.org/10.1051/bioconf/20236903017.

Lamba, P., Kaur, D.P., Raj, S. & Sorout, J. 2022. Recycling/reuse of plastic waste as construction material for sustainable development: a review. *Environmental Science and Pollution Research*, 29, pp.86156-86179. Available at: https://doi.org/10.1007/s11356-021-16980-y.

Moulai Arbi, Y., Mahmoudi, N. & Bentahar, M. 2024. Evaluating the structural performance of masonry walls incorporating recycled plastic bricks under monotonic and cyclic loading. *Vojnotehnički glasnik/Military Technical Courier*, 72(3), pp.1306-1344. Available at: https://doi.org/10.5937/vojtehg72-50560.

Moulai Arbi, Y., Mahmoudi, N. & Djebli, A. 2023. Manufacturing and testing of waste PET reinforced with sand bricks. *Journal of Composite Materials*, 57(16), pp.2513-2526. Available at: https://doi.org/10.1177/00219983231175203.

Patil, G.N., Al Yahmedi, M., Walke, S.M. & Rao, L. 2020. Manufacturing of plastic sand bricks from polypropylene and polyethylene waste plastic. *International Journal of Advanced Science and Technology*, 29(08), pp.2062-2068 [online]. Available at: http://sersc.org/journals/index.php/IJAST/article/view/23320 [Accessed: 29 July 2024].

Qin, W., Li, S., Bai, H. & Jia, S. 2024. Structural design and heat transfer analysis of twin-screw extrusion 3D printer. *The International Journal of Advanced Manufacturing Technology*, 130, pp.5601-5618. Available at: https://doi.org/10.1007/s00170-024-13010-2.

Reichel, H. & Krause, R. 2016. Investigation and Prognosis of Waste Heat Occurrence during the Extrusion Process of Tubular Profiles. *AMM - Applied Mechanics and Materials*, 856, pp.209-216. Available at: https://doi.org/10.4028/www.scientific.net/amm.856.209.

Thatheyus, A.J., Kandasamy, M., Sivarethinamohan, S., Ramakrishan, D. & Suresh, V. 2020. Utilization of plastic waste and polystyrene in making light weight red soil fly ash bricks. *IOP Conference Series: Materials Science and Engineering*, 955, art.number:012055. Available at: https://doi.org/10.1088/1757-899X/955/1/012055.

Diseño y funcionamiento de una extrusora manual para adoquines compuestos de ladrillo plástico reciclado

Abdelkader Daikh[a], *Youcef* Moulai Arbi[b], **autor de correspondencia**, *Mohammed* Bentahar[c], *Noureddine* Mahmoudi[c]

[a] Universidad de Mustapha Stambouli, Facultad de Tecnología,
Departamento de hidráulica,
Mascara, República Argelina Democrática y Popular

[b] Universidad de Mustapha Stambouli, Laboratorio de Física Cuántica de Materia y Modelamiento Matemático (LPQ3M),
Mascara, República Argelina Democrática y Popular

[c] Universidad de Saida Dr. Moulay Tahar, Facultad de Tecnología,
Departamento de Ingeniería Civil e Hidráulica,
Saida, República Argelina Democrática y Popula

CAMPO: ingeniería mecánica, ingeniería civil
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Este estudio tuvo como objetivo desarrollar una extrusora manual de ladrillos de plástico rentable para fabricar ladrillos compuestos a partir de polipropileno reciclado y polvo de ladrillo. El objetivo era abordar los desafíos de la vivienda en los países en desarrollo y al mismo tiempo promover la gestión sostenible de residuos.

Métodos: Se fabricó una extrusora de un solo tornillo con matriz de 60 mm, con manivela manual, sistema de calentamiento y tolva. Se produjeron especímenes compuestos con diferentes proporciones de polipropileno (30-80 porcentajes en peso) y polvo de ladrillo (20-70 porcentajes en peso). Se realizaron pruebas mecánicas, incluidas mediciones de resistencia a la compresión, resistencia a la flexión, resistencia al impacto y densidad.

Resultados: La mezcla de polvo de ladrillo y polipropileno 40:60 exhibió una resistencia a la compresión óptima, que oscilaba entre 23,76 y 24,90 MPa. La resistencia a la flexión alcanzó su punto máximo en la proporción 50:50 (11,86-12,5 MPa). La resistencia al impacto disminuyó al aumentar el contenido de polvo de ladrillo. La densidad aumentó linealmente con el contenido de polvo de ladrillo, oscilando entre 1,48 y 1,77 g/cm³. La extrusora produjo con éxito muestras compuestas uniformes en todas las mezclas.

Conclusión: El estudio demostró la viabilidad de producir ladrillos compuestos utilizando una extrusora manual de bajo costo. Se identificaron dos composiciones de mezcla óptimas: 40:60 polipropileno:polvo de ladrillo para una máxima resistencia a la compresión y 50:50 para una resistencia óptima a la flexión. Este enfoque ofrece una solución prometedora para la construcción de viviendas asequibles y al mismo tiempo aborda la gestión de residuos plásticos en las regiones en desarrollo. Las investigaciones futuras deberían centrarse en optimizar el proceso de extrusión, explorar *materiales de desecho adicionales y realizar estudios de durabilidad a largo plazo de los ladrillos compuestos.*

Palabras claves: extrusora manual, polipropileno, polvo de ladrillo, compuesto, adoquines.

Разработка и производительность ручного экструдера для производства композитной брусчатки из переработанного пластика и кирпичной крошки

Абделкадер Даих[а], *Юсуф* Мулаи Арби[б], **корреспондент**,
Мухаммед Бентахар[в], *Нуредин* Мамуди[в]

[а] Университет Мустафы Стамбули, технологический факультет,
кафедра гидравлики,
г. Маскара, Алжирская Народная Демократическая Республика

[б] Университет Мустафы Стамбули, лаборатория квантовой физики материи и математического моделирования (LPQ3M),
г. Маскара, Алжирская Народная Демократическая Республика

[в] Университет Саиды „Доктор Мулай Тахар“, технологический факультет,
кафедра гражданского строительства и гидравлики,
г. Саида, Алжирская Народная Демократическая Республика

РУБРИКА ГРНТИ: 67.11.00 Строительные конструкции
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Целью данного исследования была разработка экономичного ручного экструдера для производства пластиковых композитных кирпичей из переработанного полипропилена и кирпичной крошки. Целью исследования было решение жилищного строительства в развивающихся странах при одновременном содействии устойчивому управлению отходами.

Методы: Был изготовлен одношнековый экструдер с матрицей диаметром 60 мм, оснащенный ручкой для ручного поворота, системой нагрева и соплом. Также изготовлены образцы композитов с различным соотношением полипропилена (30-80 мас.%) и кирпичной крошки (20-70 мас.%). Проведены механические испытания, в том числе измерения прочности на сжатие, изгиб, ударопрочность и плотность.

Результаты: Смесь полипропилена и кирпичной крошки в соотношении 40:60 продемонстрировала оптимальную прочность на сжатие, составив 23,76-24,90 MPa. Прочность на изгиб достигла своего пика при соотношении 50:50 (11,86-12,5 MPa). Ударопрочность снижалась с увеличением содержания кирпичной крошки. Плотность линейно возрастала с *увеличением содержания кирпичной крошки, составляя от 1,48 до 1,77 г/см3. С помощью экструдера были успешно получены однородные образцы композита из всех смесей.*

Вывод: Исследование показало возможность производства композитного кирпича с использованием недорогого экструдера с ручным управлением. Были определены два оптимальных состава смеси: полипропилен и кирпичный порошок в соотношении 40:60 для обеспечения максимальной прочности при сжатии и 50:50 для обеспечения оптимальной прочности при изгибе. Этот подход предлагает многообещающее решение для доступного жилищного строительства и решения проблемы утилизации пластиковых отходов в развивающихся регионах. Будущие исследования должны быть направлены на оптимизацию процесса экструзии, изучение дополнительных отходов и проведение исследований долговечности композитных кирпичей.

Ключевые слова: ручной экструдер, полипропилен, кирпичная крошка, композит, брусчатка.

Пројектовање и перформансе ручног екструдера за композитне цигле за поплочавање од рециклиране пластике и цигленог праха

Абделкадер Деих[а], *Јусуф* Мулаи Арби[б], **аутор за преписку**,
Мухамад Бентахар[в], *Нуредин* Мамуди[в]

[а] Универзитет „Мустафа Стамбоули”, Технолошки факултет,
Одељење за хидраулику,
Маскара, Народна Демократска Република Алжир

[б] Универзитет „Мустафа Стамбоули”, Лабораторија за квантну физику
материје и математичко моделирање (LPQ3M),
Маскара, Народна Демократска Република Алжир

[в] Универзитет у Саиди „Др Мулаи Тахар”, Технолошки факултет,
Департман за грађевинарство и хидраулику,
Саида, Народна Демократска Република Алжир

ОБЛАСТ: машинство, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Циљ ове студије био је развој исплативог ручног екструдера пластичних цигли за производњу композитних цигли од рециклираног полипропилена и цигленог праха. Примена овог материјала учинила би за изградњу станова у земљама у развоју економичнијом, уз истовремени допринос одрживом управљању отпадом.

Методе: Израђен је једнопужни екструдер с матрицом од 60 тт, ручком за мануелно окретање, системом за грејање и грлом за *увлачење. Произведени су узорци композита са различитим односима полипропилена (30–80 тежинских процената) и цигленог праха (20–70 тежинских процената). Извршена су механичка испитивања чврстоће на притисак, чврстоће на савијање, отпорности на удар и обављано мерењегустине.*

Резултати: Смеша полипропилена и цигленог праха у односу 40:60 показала је оптималну чврстоћу на притисак у распону од 23,76 до24,90 MPa. Чврстоћа на савијање достигла је највећу вредност при односу 50:50 (11,86–12,5 MPa). Отпорност на удар се смањивала с повећањем садржаја цигленог праха. Густина се линеарно повећавала са садржајем цигленог праха у распону од 1,48 до1,77 g/cm^3. Екструдер је успешно произвео униформне композитне узорке свих смеша.

Закључак: Студија је показала да је изводљиво произвести композитне цигле користећи јефтин ручни екструдер. Идентификована су два оптимална састава смеша: полипропилен и циглени прах у односу 40 према 60 за максималну чврстоћу на притисак и 50:50 за оптималну чврстоћу на савијање. Овај приступ нуди решење за економичну стамбену изградњу, уз допринос управљању пластичним отпадом у земљама у развоју. Будућа истраживања би требало да се фокусирају на оптимизацију процеса екструзије, истраживања додатних отпадних материјала и на спровођење студија дугорочне издржљивости композитних цигала.

Кључне речи: ручни екструдер, полипропилен, циглени прах, композит, цигле за поплочавање.

Paper received on: 30.07.2024.
Manuscript corrections submitted on: 16.11.2024.
Paper accepted for publishing on: 18.11.2024.