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A quad-cliff mechanism for eco-printing by pounding technique: design, manufacturing, and testing

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Abstract

Indonesia produces many types of textile products, such as clothing and custom fabrics often with unique patterns. To generate the patterns, there are many methods, including eco-printing by pounding process. However, the process, which was later referred to as eco-pounding, requires much time and energy, which can have a negative impact, such as musculoskeletal disorders, on the human body. To address this issue, the present work proposes a machine that can help the process of eco-pounding. Shigley's method is applied to guide the design process of the machine. The design and manufacturing processes of the eco-pounding machine are presented, in which three machine design models are first introduced and then analyzed for finalization by benchmarking method. Subsequently, a machine model that uses a so-called quad-cliff mechanism is selected for manufacturing and testing. As a result, the proposed machine can achieve the design requirements that were set. Three pounding movements per second can be obtained by the machine, with possible increases by an engine upgrade. This machine can be considered a prototype for a semi-automatic eco-printing process by pounding technique.

Keywords:

Eco-printing machine, pounding technique, quad cliff mechanism.

1 Introduction

As one of the top ten textile-producing countries, the textile product industry has become important for Indonesia's economic growth, poverty elimination, and generating job for many people [1], [2]. There are various things made up of textiles, such as clothing, doormats, custom fabrics, and many more. To make patterns for those textile products, several things can be done, such as batik or eco-printing processes [3]. Of the two options, eco processes, including eco-printing, has gained attention due to its sustainability compared to traditional batik processes [4], [5].

Eco-printing is a way to make unique, natural, and authentic patterns in fabrics that utilize materials from the natural environment such as leaves, flowers, wood, roots, or other parts of a plant that contain color pigment [6], [7]. Those parts of plants can give distinctive color or pattern to the fabric that is going to be used. To get the patterns, some techniques need to be applied to the fabric, such as pounding or beating, steam, iron blanket, and many more [8], [9]. This is one of the most popular methods to teach the local populace to boost their economy [10].

The easiest and most common technique of eco-printing is the pounding (beating) technique [8]. This technique, later referred to as eco-pounding in this paper, is done by putting the collected part of the plants to the fabric, then beating it using a hammer until the natural color appears and is printed onto the fabric [11], [12]. This technique can emit a more vibrant color but requires more energy since the natural materials are beaten manually by using hammer [11]. Moreover, it takes a lot of time and is labor-intensive just to make one craft [13], [14].

Based on research that was conducted on the hammering workers, it is found that most of them are affected by musculoskeletal disorders, a condition that can affect any part of the body that involved in movement, such as the neck, shoulders, wrist, back, or any other places [14], [15]. Even though it has negative impacts on health, is time consuming, and requires a lot of energy, many communities, small-medium enterprises, and artisans from all over the world still make this craft their livelihood or as a side job [15], [16]. As a result, it might be hard for those people to meet the demand that keeps growing in the textile and sustainable industries [17], [18].

In order to help people in the eco-pounding industry, a Focus Group Discussion (FGD) was done with a group of small-medium enterprises named Lenteng Agung Sejahtera (Lentera SME). It was revealed that a machine to help with eco-printing or eco-pounding activity is demanded. The machine is expected to minimize the manual work by hand, which in return can make a more productive and less labor-intensive working process [14], [19]. Moreover, the machine needs to do a pounding movement just like a person normally does with a rate of at least a half, equal, or even faster than that of a human hand. Then, the machine is expected to reduce the energy and time for production, with nonetheless does not eliminate the cultural aspects of the eco-printing itself. This cultural aspect, which is the optional requirement, includes full human control for the location of the natural materials on the fabric or the pattern to be made, the type of hammer to be used, and the place where the hammer should hit the fabric.

The purpose of this work is to design and to manufacture an innovative eco-pounding machine prototype to be used in eco-pounding industries. The machine was developed by following the Shigley design method, which includes the process of identifying the needs, defining the problem, developing the machine designs, analyzing, and making the machine of the chosen design [20]. To make the design and build the machine, Computer-Aided Design (CAD) software is used. The manufacturing was done by additive manufacturing using FDM 3D printers and conventional subtractive manufacturing [21], [22]. The machine prototype is expected to help the people who work or want to join the eco-pounding industry by reducing the time and energy needed in the making process.

2 Research Methods

The present work used the Shigley method as the guideline for the design and development process, which allows the design to have clear goals, criteria, and limitations. The Shigley model is one of the most popular models of the design process due to its structured and systematic approach to the design [20]. Fig. 1 illustrates the six stages of Shigley's model of the design process. The main process starts with the identification of needs and ends with the presentation. The process can also be iterated from one stage to the next if needed.

Shigley design process consists of six stages. It begins with the identification of needs stage, recognizing a problem that may be solved by the proposed design or product. The problem then translates into the second stage, which is the definition of the problem. At this stage, the criteria and limitations of the design, such as specifications, are defined. Those specifications may include dimensions, cost, function, and quality. Following the specified core specifications, the product or design then synthesizes in the third stage with a possible additional feature. The synthesized designs were then analyzed and optimized in the fourth stage to ensure they met the specification. The promised design moved to the fifth stage to be evaluated to ensure it meets the specification defined in the first stage. The evaluation might involve fabrication or testing the design for its performance, quality, and reliability. Importantly, each of the stages can be revisited and reevaluated as needed. The sixth stage is the presentation of the solution, which might include presenting the model, publishing to the academic journal, and/or encompassing design documentation.

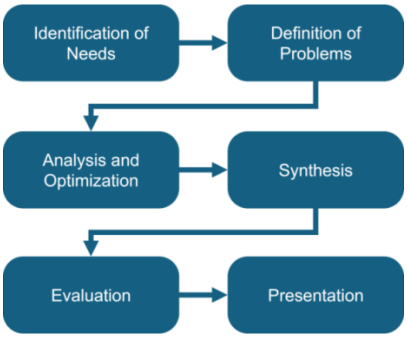


Fig. 1. Shigley's model of the design model.

2.1 Identification of Needs and Problem Definition Process

The identification of the need process is done after the FGD process with Lentera SME. Based on the FGD process, the criteria or features that are needed for the machine are listed in Table 1. These features are then given weight and category in order of their importance to the overall machine design.

Table 1. Machine specification

Category	Specification	Weighted
Must have (primary)	Hammer works automatically with a minimum of 6.5 N force	20
	Can do hammering with a minimum of 150/min	20
Nice to have (secondary)	Size of the product (less than 70×30×30 cm)	15
	Number of moving parts	15
	Replaceable hammerhead	10
	Mass < 5 kg	10
Nice to have (tertiary)	Environmentally friendly	5
	Accessible by anyone	5
Total		100

2.2 Synthesis and Design Process

After deciding the criteria or specifications, some designs of the machine were created by utilizing CAD software. Initially, there are three proposed designs, as shown in Fig. 2; two are hammer-based and one is roller-based.

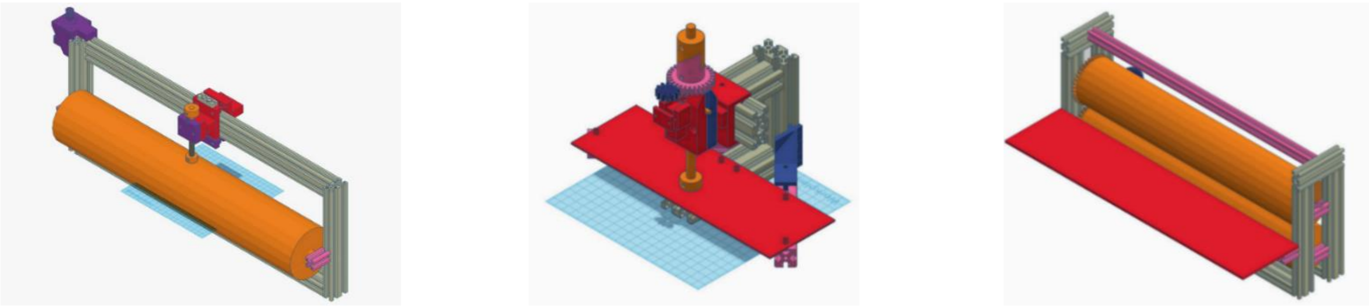

(a) (b) (c)

Fig. 2. Design of the machine: (a) design 1, (b) design 2, and (c) design 3.

Design 1, shown in Fig. 2(a), was the most complicated yet the most automated machine that was proposed. It used a similar method of working from 3D printing, with the head changed to a hammer for pounding action. The base of the machine was also changed to a roller that can automatically move the fabric.

Design 2, shown in Fig. 2(b), was the derivative of design 1. The difference is located at the core hammering component, which is fixed to a structure. Therefore, only the hammer will be moving up and down, which simplifies the design and allows the human operator to fully control the leaf placement and design process manually. Moreover, this design is similar to a sewing machine.

Design 3, shown in Fig. 2(c), was a novel design. This design uses a roller type that relies on compression between the two rollers as the leaf and cloth are inserted into one of the rollers, before it is then tightened and let it be rolled. This allows an incredibly rapid turnover rate between each cloth while still retaining the human to fully control the leaf placement on the cloth.

2.3 Analysis and Optimization Process

With the three proposed designs, a benchmarking process was conducted to choose the most promising design. This process was done by utilizing Pugh Matrix, which uses criteria scoring to find the potential best solution for the selected items [23], [24]. The Pugh Matrix benchmarking process is done by choosing one arbitrary design as the current solution and the other designs as the alternative solution. The current solution will be given 0 points, while the alternative will be given either -1, 0, or 1, depending on the comparison of the performance or feature to the current solution. It can be used to determine the potential or alternative solutions to some problems.

In the current project, design 2 is chosen arbitrarily as the current solution, while the other designs are the alternative solutions. The result of the benchmarking is shown in Table 2. The result shows that design 2 leads the point, fitting to the needs of the project, and therefore is developed further.

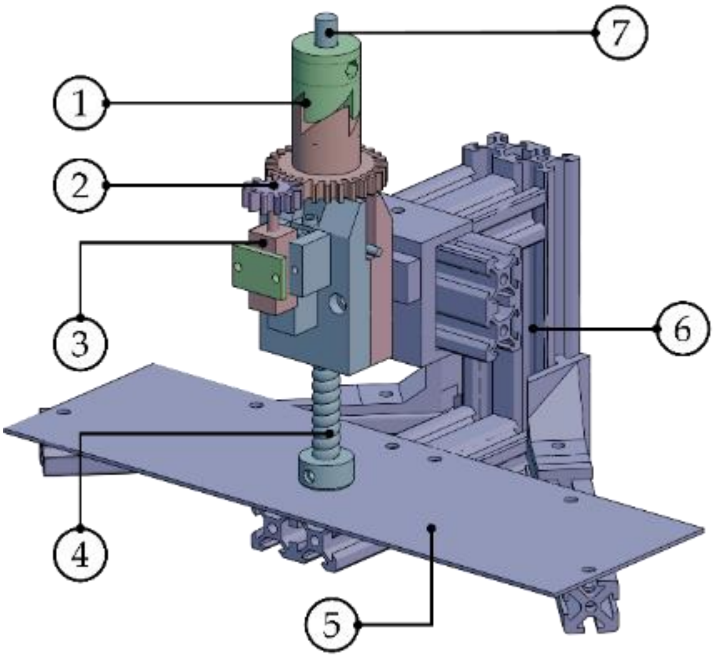
Table 2. Benchmarking process

Criteria	Weight	Design 1		Design 2		Design 3	
		Score	Total*	Score	Total	Score	Total
Hammer works automatically with min. 6.5 N	20	0	0	0	0	-1	-20
Hammering min. 150/min	20	-1	-20	0	0	-1	-20
Size of the product (not more than 70×30×30 cm)	15	0	0	0	0	0	0
Number of moving parts	15	-1	-15	0	0	-1	-15
Replaceable hammerhead	10	0	0	0	0	-1	-10
Mass < 5 kg	10	0	0	0	0	0	0
Supports the idea of eco-pounding (environmentally friendly)	5	0	0	0	0	0	0
Accessible by anyone (age-range, gender)	5	1	5	0	0	1	5
Total			-30		0		-60

*Total = Weight × Score

2.4 Evaluation Process

The evaluation of the design was done by manufacturing the design. Design 2, the chosen design, has several main parts that can be gathered by self-fabricating or using the off-the-shelf parts. The main parts of the design as show in Fig. 3.



#	Description
1	Quad cliff clicking mechanism
2	Reduction gear
3	Motor
4	Hammer and spring
5	Base
6	Machine supports
7	Stabilizer rod

Fig. 3. The chosen design of the machine and the parts description.

Table 3 shows the self-fabricated parts for the design. The project used the FDM 3D printing manufacturing process using PLA as its material for the rear chassis, front chassis, and motor holder. The FDM printing method was chosen due to its cost and reliability, including its durability, stability, and sustainability [25], [26]. These advantages makes it suitable for use in an early proof-of-concept stage product.

Table 3. Self-fabricated parts quantity and process

Part name	Qty	Material	Fabrication
Front chassis	1	PLA	3D printing
Rear chassis	1	PLA	3D printing
Motor holder	1	PLA	3D printing
Driving gear	1	PLA or aluminum	3D printing
Hammer head	1	PLA or aluminum	3D printing or turning
Bottom cliff mechanism	1	PLA or aluminum	3D printing or milling
Top cliff mechanism	1	PLA or aluminum	3D printing or milling
2040 connector block	1	PLA	3D printing
Adapter block	1	PLA	3D printing
45 degree 2020 bracket	2	PLA	3D printing

The slicing of the parts is done using Simplify3D software with a custom preset optimized for balance between time and quality, as each of the parameters will determine the properties of the printed parts [27]. The average print speed used is 40 mm/s, while the layer height and nozzle width were 0.2 mm and 0.4 mm, respectively, to ensure part strength. All the parts were printed on Anycubic I3 Mega and Anycubic Kossel FDM printers.

Besides the self-fabricated parts, there are also off-the-shelf parts that are used in the design. The list of the off-the-shelf parts, including the quantity, size, and processing of the parts is available in Table 4.

Table 4. Part list

Part name	Qty	Size (mm)	Note
2020 aluminum profile	1	300	Cut into 2×150 mm
2040 aluminum profile	1	390	Cut into 120 mm, 100 mm, and 50 mm
8 mm round bar 304 steel	1	180	Bore three 3.5 mm holes with distance of 4 mm, 90 mm, and 160 mm from the bottom position
8 mm linear bearing LM8UU	1		
40 mm 10 mm ID 1 mm steel spring	1		
M4 8 mm 304 steel screw FT	10		
M4 50 mm iron screw FT	2		
M8 flat washer	1		
M4 T-Nut	18		
M3 15 mm 304 steel JF	2		
M3 50 mm 304 steel HT	1		
M3 iron hex nut	3		
90 degree 2020 T slot bracket	6		
304 steel plate	1	260×85	
N20 motor with 1:300 reduction gear	1		
PWM 1803BK ESC	1		
DC 12V 5A adaptor	1		

2.5 Performance Testing

After the manufacturing process, the machine is tested for its performance. The first performance test is the pounding frequency of the machine to ensure that the machine can do the required pounding movement with the desired speed. The measurement was done by recording the sound of the working machine for ten seconds. Each of the spikes from the waveform is considered as one pounding action from the machine. Total pounding action for ten seconds is counted, and the average pounding frequency per second is calculated.

Besides pounding frequency, the machine is also tested for its printing performance to ensure the machine's reliable printing capability. The printing performance of the machine was done by testing the pounding mechanism to print color and pattern from kalpataru leaf on calico fabric. Calico fabric, also known as *blacu* or *belacu* fabric, is a type of fabric that is made from natural cotton and does not go through the fabric processing process [28], [29], [30]. This type of fabric is commonly used due to its eco-friendly and durable nature. The result of the printing was then compared to the result of printing from the manual pounding technique.

3 Results and Discussion

The presentation of the machine result is divided into two sections, which are machine fabrication and testing. Machine fabrication discusses about the fabrication and the performance of the machine against the required design parameters. After that, the machine testing discusses the tests that were done to the machine, namely pounding frequency and printing performance of the machine.

3.1 Machine Fabrication

The machine was successfully built, and the result of the performance analysis on the finished prototype. The dimension of the prototype is 20.6 cm height, 16 cm long, and 27.5 cm wide, as shown in Fig. 4. The machine has a mass of 1 kg, lower than the maximum mass limit of 5 kg from the requirement.

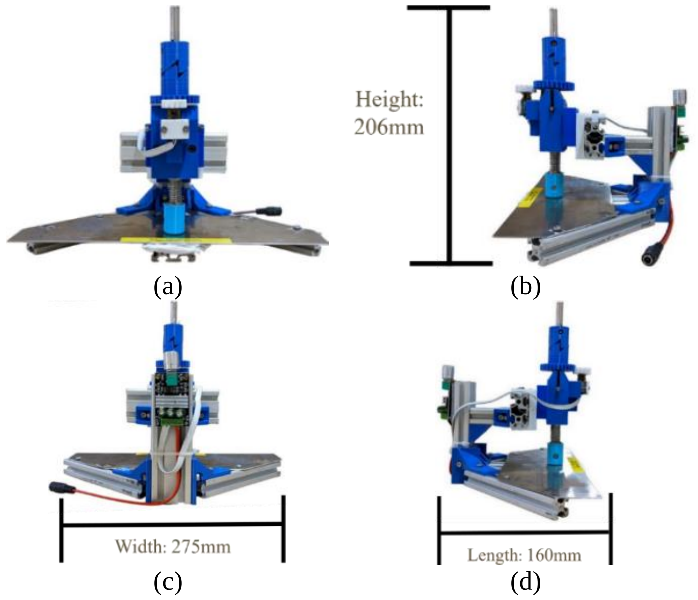


Fig. 4. Assembled view of the machine: (a) front, (b) right, (c) back, and (d) left side.

The so-called "quad-cliff" mechanism was used in this machine to deliver the hammering action, as shown in Fig. 5. This mechanism works by combining torque with normal force with the electric motor driving a gear which turns counterclockwise. The driving gear will turn the driven gear and bottom cliff mechanism clockwise, lifting the top mechanism that is fixed by a 50 mm stabilizer rod in the mechanism main body. It will be counteracting the torque and turning it into a normal force that pushes the top cliff mechanism upwards. As the top mechanism lip reaches a cliff of the bottom mechanism, it will accelerate downwards assisted by the spring, releasing the stored energy in a 6.5 N hammering action. The machine motor operates by using a 12 V power source with a DC barrel jack that inserts into the electronic speed controller. With this, the speed of the mechanism can be controlled to the user's desired speed.

Fig. 5. Quad cliff clicking mechanism.

The hammering characteristic can be modified by changing the spring type, thickness, and material of the hammer. There is also a possibility to modify the height of the hammer head by using screws in the 3D model. However, this is an optional feature that is not implemented in this prototype. For the operation, the user can insert the leaf and fabric underneath the hammer as it is in the raised position and move both the leaf and fabric slowly as the machine hammers and imprints the dye and pattern of the leaf to the fabric.

Fig. 6 shows the eco-pounding process using this machine, in which the hammerhead punches a leaf on a fabric product.

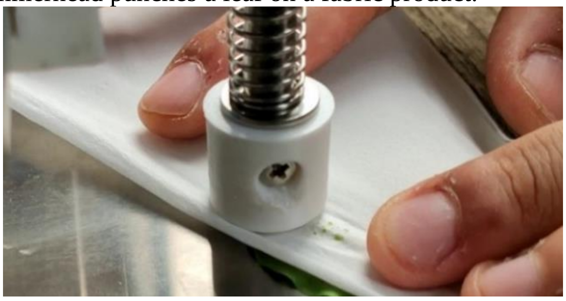


Fig. 6. The machine is performing an eco-pounding process.

The core "quad-cliff" mechanism of this machine can operate both with and without the frame, allowing the customization of the hammer itself. Customizing the frame and all design parameters can also be done in accordance with the user's case and needs. For example, the hammerhead can be replaced easily by different sizes or shapes. Hence, the whole design of this machine can be interpreted as a modular and flexible design. This modular and flexible design allows the machine to scale up if needed.

The machine meets the requirements as it operates in an environmentally friendly way, similar to the conventional counterpart. It produces no pollution, which makes it a sustainable choice. The machine is also accessible to a wide range of users due to the simple fabrication process. However, for a child's safety, it is recommended for the presence of adult supervision when the machine is operated.

3.2 Performance Testing

The performance of the machine is tested by two methods, which are the pounding frequency and the printing product. The pounding frequency is measured by recording the sound of the working machine. Fig. 7 shows the waveform of the recording for one minute at three pounding speeds. Every peak of the waveform indicates a pounding action by the hammer.

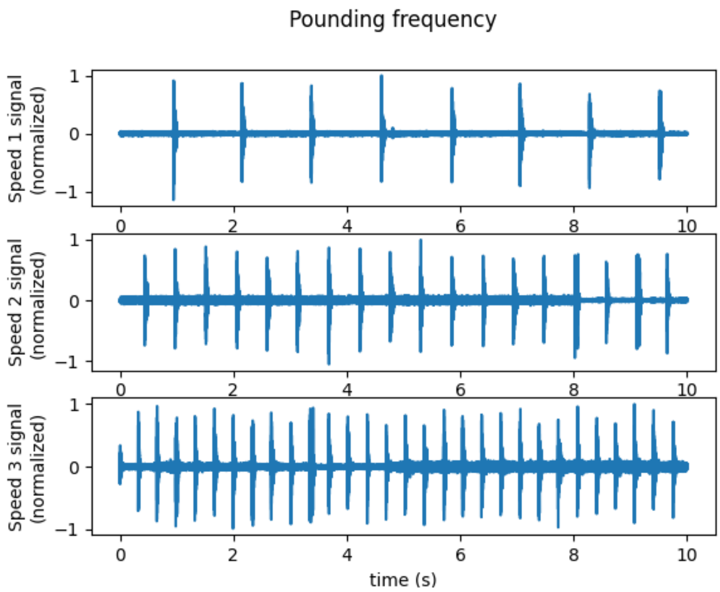


Fig. 7. Pounding frequency of the machine in three speeds.

According to Fig. 7, the machine can do pounding action with an average frequency of 0.8 to 3 poundings per second. This means that it can weigh up to 180 poundings per minute. This performance exceeds the minimum pounding frequency requirement that was set.

Besides the pounding frequency, the machine was also tested for its printing performance. From the test, the machine is capable of producing comparable printing results to the manual process, as shown in Fig. 8. The printing result looks sharper with the machine, especially on the venation of the leaf. Besides, it looks more muted than the result from the manual process. The difference may be because of the quality of the leaf [31], [32], and the position of the leaf against the fabric [33]. This can be improved by more practice in using the machine or by improving the design of the machine.

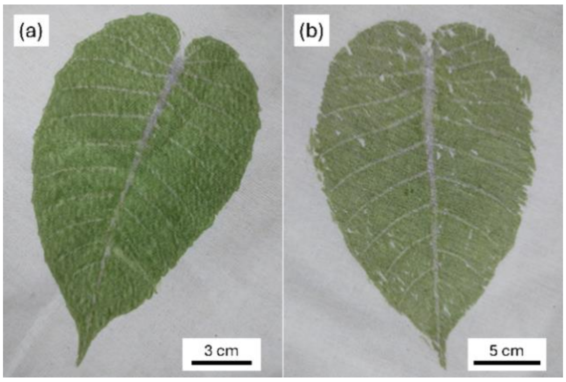


Fig. 8. Printing result by (a) hand and (b) machine.

Based on comments from potential users in the Lentera SME, the recommendations mostly address the small workplace area of the machine and static position of the demonstrator unit. It is indicated that making the machine head move as opposed to the fabric would be also beneficial for the human operator. The scaled-down nature of the prototype means that it only has an effective work surface of 20 cm and 14 cm in width and length, respectively, with a suboptimal working system. As a future plan, a development to scale up the machine and to create mitigation plans for the vibration amplitude is being considered. One of the candidates for that future development is making it a wall-mounted and fixed vertical-position arm machine with a free-moving horizontal hinge to reduce the vibration effect.

4 Conclusion

This work presents a compact machine prototype for the eco-printing process by pounding technique also referred to as an eco-pounding machine. This machine has a dimension of 20.6 cm height, 16 cm long, 27.5 cm wide, and 1 kg of mass. It employed a novel quad-cliff mechanism with a fixed hammerhead, enabling the machine to have a pounding mechanism up to 3 poundings per second (180 poundings per minute), exceeding the required 150 poundings per minute. This innovative quad-cliff mechanism design allows the hammer of the machine to be customized by different sizes and shapes, which makes the machine modular and flexible. Furthermore, the force exerted by the spring and hammer is able to produce comparable printing results compared to the manual process. This work presents a successful proof-of-concept of an innovative automatic eco-pounding machine as a reference for further development and potential implementation in the eco-printing industry.

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