DRAINKER PROJECT: PERMEABLE CERAMIC PAVING FOR SUDS

J. Mira [1], J. Corrales[1], L. Vilalta[1], E. De Miguel [2], E. Fernandez-Vivancos[2], I. Andrés-Doménech[3]

ITC-AICE, Spain
[1] Instituto de Tecnología Cerámica (ITC). Asociación de Investigación de las Industrias Cerámicas (AICE) - Universitat Jaume I. Castellón. Spain.
[2] Ceramic Tile Studies Department of Valencia. Universitat Politècnica de València. Valencia. Spain.
[3] Instituto de Investigación de Ingeniería del Agua y Medio Ambiente (IIAMA). Universitat Politècnica de València. Valencia. Spain.

ABSTRACT

The continuous and rapid growth of our cities, which brings with it progressive waterproofing of the soil, is seriously altering the hydrological cycle and generating an increase in runoff volumes with high peak flows and very short response times, which can jeopardise the proper functioning of drainage and sanitation systems in urban environments. This comes in addition to a growing risk of droughts and episodes of torrential rains caused by climate change and together make seeking a new approach for more efficient and sustainable management of urban rainwater runoff necessary.

In this regard, Sustainable Urban Drainage Systems (SUDS) offer solutions to solve current and future challenges in urban drainage. There are multiple types of such systems, all of which are classified as nature-based solutions, including vegetation-covered roofs, filter strips, green ditches, detention tanks or permeable surfaces, among others.

The present project concerns this last category and aims to develop permeable ceramic paving with high draining capacity made by assembling ceramic tiles manufactured to circular economy criteria such that it can be assembled and installed practically dry, thus adding to the product's entire useful life (maintenance, repair, recovery, reuse or valorisation). The results obtained will be notified to all companies manufacturing ceramic tiles in order to encourage their manufacture and use in public works, as well as in the outdoor urbanisations of land plots. The secondary objectives of the project include validating the following:

- Technical characteristics of the ceramic tiles to be manufactured. The tiles shall have a thin cross-section and large edge and need to meet the demands of urban life in terms of satisfactory bending strength, resistance to impacts and abrasion, and low water absorption in order to successfully address those demands.
- Tile assembly process to produce permeable paving.
- Permeable paving behaviour. To test this, a mock demonstration unit will be set up in a significant outdoor environment and monitored to assess its performance from the point of view of installation, durability and surface permeability.

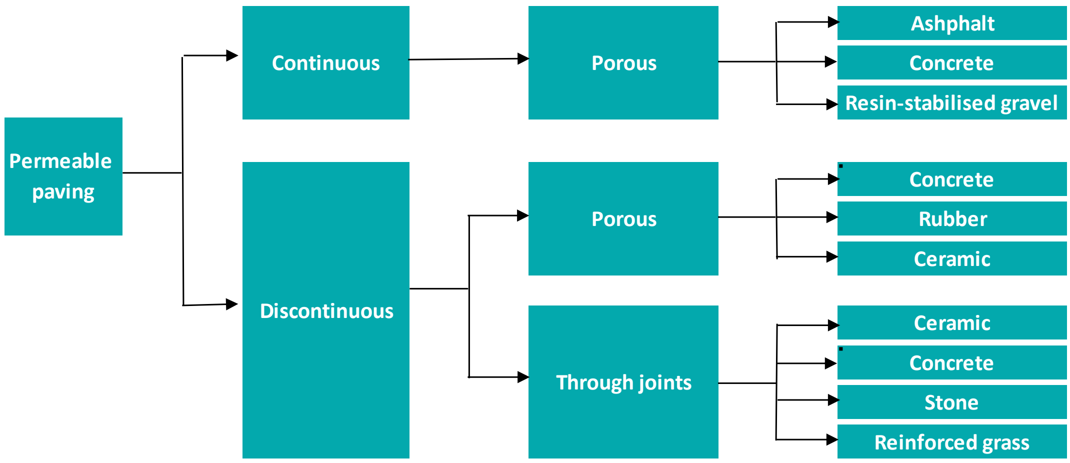
This paper presents the initial results up to September 2023 of the DRAINKER project, which started in November 2022 and is planned to run for 24 months. The paper focuses principally on the design of the permeable paving and leaves the processes involved in assembly of the pieces, results of laboratory validation tests, and design and construction of the mock unit to be dealt with in a subsequent paper.

The **DRAINKER project (INNVA1/2022/12)** is being funded by the **Valencian Innovation Agency (AVI)**.

INTRODUCTION

Permeable paving probably represents one of the most complete SUDS techniques for solving current and future problems in terms of urban drainage, as it allows both control of runoff at source, its lamination, and treatment of its quality, mainly by filtration. At present, there are several types of permeable paving, which include the following: permeable pavers, porous asphalt, reinforced grass, resin-stabilised gravel, and porous concrete, amongst others[1]. These alternatives can be divided into two large groups - continuous permeable paving and discontinuous paving, as illustrated in the following diagram:

[1] Woods Ballard, B. et al (2015). The SuDS Manual (C753F). CIRIA. ISBN: 978-0-86017-759-3. Available at: https://www.ciria.org/Memberships/The_SuDs_Manual_C753_Chapters.aspx



Continuous permeable paving allows water to drain because it contains porous materials (concrete or asphalt). In the case of discontinuous permeable pavements, drainage is achieved by using porous materials or through the joints between components. Discontinuous permeable paving systems are being used more frequently in pedestrian areas in urban environments, as well as in urbanisations of land plots, and usually comprise pavers or slabs that are installed dry. Chief among current materials on the market are permeable concrete pavers, while ceramic, stone or rubber materials can also be found, but to a lesser extent.

Concrete pavers can be either porous or permeate through the joints. Although such products offer good flexural performance, their main limitations are durability and draining capacity. In this sense, it is important to note that the minimum recommended initial permeability for permeable paving is 2,500 mm/[11]h[11], a value that is met by very few products.

As far as ceramic materials are concerned, the commercial products to be found on the market, although much less widespread than permeable concrete products, are pavers that permeate through the joints and other porous paving systems made from waste. In the case of permeable ceramic pavers, some international manufacturers have been located, while in Spain, the only product to be found is Flexbrick[2], which can be used as draining ground cover in green spaces or rooftops, among other applications. This type of product, although offering better mechanical performance and durability than concrete paving, has very limited permeability, a property that manufacturers do not declare on their product sheets.

The origin of the paving proposed here is the LIFE CERSUDS European project (LIFE15 CCA/ES/000091), characterised by the use of ceramic tiles of low commercial value (in stock), which, once cut, are assembled edge-on with the use of cementitious adhesive in strips to obtain a ceramic module that is permeable through its multiple joints. The paving in this project, which has been co-ordinated by Spain's Institute of Ceramic Technology (ITC), offers very high initial permeability levels of over 15,000 mm/h but has a series of limitations or barriers from the point of view of size and strength.

[2] https://www.flexbrick.es/

REGULATIONS

At regulatory level, European and national legislation promotes the transition to a sustainable and more efficient urban environment through environmental legislation, specific examples being the 2006 Land Protection Strategy, the 2013 Green Infrastructure Strategy and its transposition at national level, the 2030 Agenda, the 2015 Sustainable Development Goals, and the 2019 European Green Deal.

Recently, changes have taken place in the regulatory framework at national, regional and municipal levels that encourage the use of SUDS, including:

- The publication in 2015 of the revised Territorial Action Plan on Flood Risk Prevention in the Valencian Community (PATRICOVA).
- The publication of Spanish Royal Decree 638/2016 amending the Regulations governing Public Water Systems.
- The Valencian Parliament 2017 Resolution 997/IX that urges the incorporation of prevention measures involving the use of SUDS in the design of green spaces in territorial land planning.
- The recent publication of municipal regulations that incorporate aspects related to SUDS in cities such as Madrid (Ordinance on the Management and Efficient Use of Water, 2006), Barcelona (Rainwater Master Plan), Valencia (Sanitation Ordinance, 2015 and the Basic Guide for the Design of Sustainable Urban Drainage Systems, 2021) and Castellon (Guide to Sustainable Drainage Systems, 2020).
- The publication, in August 2023, of Spanish Royal Decree 665/2023 amending Regulations governing Public Water Systems and re-emphasizing the use of SUDS.

For all these reasons, the permeable ceramic paving proposed herein responds to a need to adapt our cities to climate change by increasing the permeability of city paving with a product that offers higher permeability than those currently on the market.

OBJECTIVES OF THE DRAINKER PROJECT

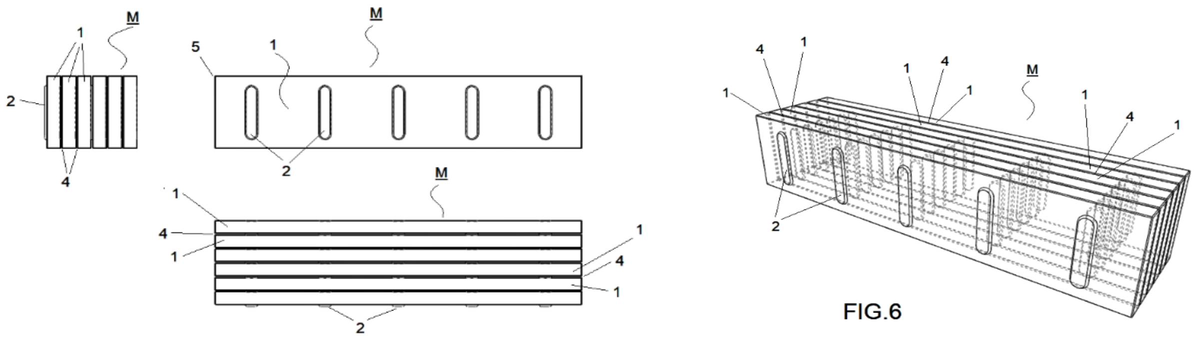
The main aim of the project is the validation of a permeable ceramic paving system, protected by the U202230202 Utility Model, intended for building SUDS and other outdoor uses to mitigate the effects of soil sealing in our cities. Such validation will make it possible to transfer this new paving solution to ceramic tile manufacturers in order to promote its commercial manufacture by one or more companies.

Therefore, it is intended to develop permeable ceramic paving with a high draining capacity, made from the assembly of ceramic tiles, manufactured to circular economy criteria in such a way that assembly and installation can be carried out practically dry and thus engage the product’s entire useful life (maintenance, repair, recovery, reuse or valorisation). The results obtained from this research will be disseminated among all ceramic tile manufacturing companies to promote its manufacture and use in public works, as well as in outdoor urbanisations of land plots. The project’s secondary aims include:

- Validation of the technical characteristics of the manufactured tiles. These tiles, with a thin cross-section and large edge, are required to meet the demands of urban spaces and therefore they must achieve appropriate levels of bending strength, impact and abrasion resistance, and low water absorption to successfully address those demands.
- Validation of the assembly process of the tiles to create a permeable paving.
- Validation of the permeable paving's behaviour. To this end, a mock demonstrator will be developed in a suitable outdoor environment and monitored to assess its performance from the point of view of installation, durability and surface permeability.

DESIGN OF THE STRIPS AND MODULES

The invention described in Utility Model U202230202 consists of a module formed by joining a number of ceramic tiles with reliefs on their front and back faces. The reliefs enable assembly and guarantee a gap between the different tiles, which are arranged in parallel to create a module. The gap between tiles is what affords the module its draining capability. The module is set on the ground, which in turn can include other drainage items, the module being positioned such that the tiles remain upright, that is, they stand on their edges.



Basic concept of the proposed paving

On the basis of that idea, the necessary requirements for this type of paving were defined and are detailed below:

Performance requirements

Characteristic	Value	Standard
Optimal permeability in the lab	> 20,000 mm/h	NLT-327/00[3]
Optimal permeability once installed	> 5,000 mm/h	NLT-327/00
Slip resistance	Class 3	UNE-EN 16165:2022[4] (Annex C and national Annex)
Transverse breaking load (T4)	80 N/mm	UNE-EN 1344:2015[5]
Impact resistance	Defects that do not compromise the paving	Annex 6 of Cahier 3778:2017
Freeze/thaw resistance	FP100 Compliance	UNE-EN 1344:2015 and UNE-EN ISO 10545-12[6]
Abrasion resistance	A3	UNE-EN 1344:2015
Dimensional tolerance	R1	UNE-EN 1344:2015
Toxicity	Must not affect the environment	Directive 67/548/EEC on dangerous substances. Regulation (EC) No. 1272/2008

Technical and/or installation-related requirements

Desired characteristic	Purpose
Variety of formats	To reduce the amount of wastage and/or operations during installation in certain configurations due to ½ formats. To be able to adapt to modulations of other pre-existing urban pavings.
Variety of configurations	Greater freedom for the specifier when it comes to proposing different paving layouts.

Environmental requirements

Desired characteristic	Purpose
Product with low environmental impacts	To define a permeable paving module that meets the required technical specifications with the minimum amount of material. Use of a ceramic composition with the lowest environmental impacts, mainly relating to the manufacturing (firing) stage.
Product designed to circular economy criteria	To make replacing the material easier in the event of breakage during its useful life. To make dismantling and reusing the paving easier if it has to be dismantled before the end of its useful life. To facilitate the separation of waste at the end of the product's useful life.

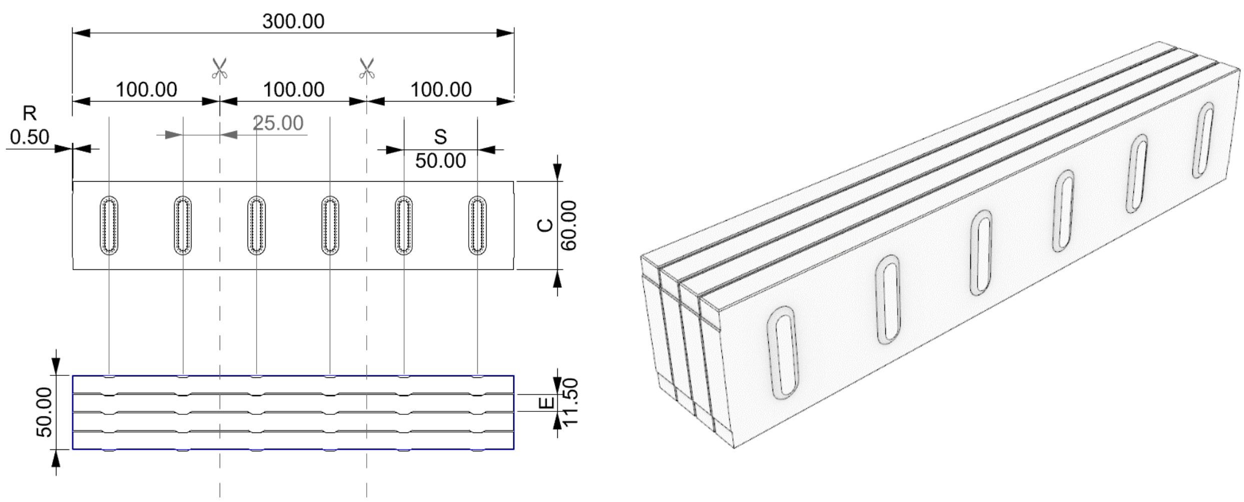
[3] NLT-327/00 In-situ permeability of draining pavements using the LCS permeameter.
[4] UNE-EN 16165:2022 Determination of slip resistance of pedestrian surfaces.
[5] UNE-EN 1344:2015. Clay pavers. Requirements and test methods.
[6] UNE-EN ISO 10545-12:1997 Ceramic Tiles - Part 12: Determination of frost resistance.

Geometrical requirements

The optimal geometry of the tiles was defined through a cyclical process to meet the requirements of intended tile use. During the process, variables such as tile format and thickness were considered, as well as the geometry and number of reliefs located on the proper face, back and treadable face of the pieces.

- Length x Width (L x A): multiples of 10 (decimal system) to adapt to the most common width measurements of pavements, crossings, disabled access regulations, etc. Initially, the creation of a single-module and a half-module tile (400 and 200 mm, respectively) was proposed. This would facilitate installation in certain types of configurations to deal with paving starts and ends.

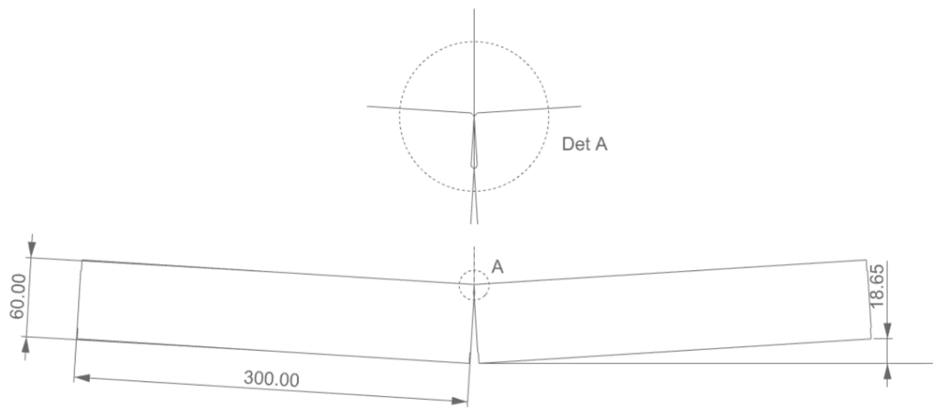
  One of the biggest constraints in terms of tile geometry was the limitations imposed by the tile manufacturing process. The process is based on pressing the tiles in a die, specially designed and made for the project. The main restriction comes from the size of the test press available to the manufacturer to produce prototypes of the ceramic tiles. The maximum length of the workpiece admitted by this press is around 300 mm, which ruled out larger-sized alternatives. Another limitation was the economic cost of manufacturing the die, which prevented a second one from being made for manufacturing half-module pieces. All this led to the development of a single module measuring 300 mm in length and 50 mm in width.



Overall dimensions and perspective view of the trial module

- Edge (C): the aim is to keep the edge as small as possible, but its full size depends on the final length of the piece. Module edge size was defined in relation to its length, taking into account its impact resistance. To decide on its size, reference was made to how the mock demonstrator in the previous Life Cersuds project behaved and so, a priori, a 60 mm edge was considered sufficient.

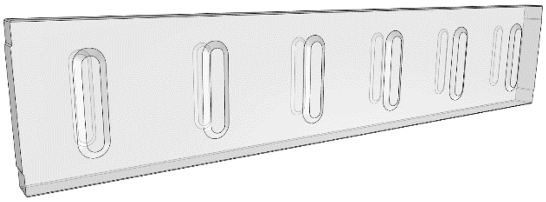
- Number of strips: an even number of strips was proposed for the permeable ceramic module and again, a priori, a total of 4 units per module were considered enough to provide it with modular proportions.
- Gap between strips: having defined the above parameters and bearing in mind the characteristics of the possible grouting material to be used and the permeability required of the ceramic module, a 1 mm thick joint between strips was established.
- Strip thickness (E): it was proposed to increase strip thickness to give the strips greater aesthetic effect and also to make it easier to treat the top surface in order to provide anti-slip properties. In view of the width of the module and the number of strips defined, strip thickness was set at 11.5 mm.
- Spacing between reliefs (S): to enable tiles to be cut in half and in thirds on site, a total of six reliefs and slots are evenly distributed along the side of the strips.
- Side recesses (R): to guarantee proper separation between modules on the shorter side and to be able to maintain a similar joint both around the perimeter of the module and between tiles, it was proposed that a recess be made in the side section. Such a recess would also prevent the appearance of certain pathologies relating to module settling after installation. It was deemed important that the tiles be designed in such a way as to prevent the module side edges from touching each other to avoid chipping or breakage. There had to be a minimum side protrusion/side spacer between modules to ensure they work properly when fitted without mortar/butt-jointed with other tiles or other urban infrastructure.
- Edge bevelling: in the same way, bevelling the edges would help to prevent contact between the sides of the tiles, which would then be less sharp and therefore less likely to spall. The image below shows how recesses and bevels can avoid such collisions with settling of less than 18 mm over a distance of 300 mm, which is a highly unlikely scenario that would entail a serious pathology.



Settling needed for tiles to come into contact

Reliefs on the tiles

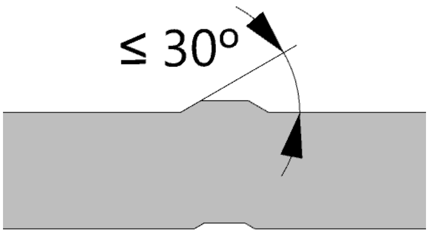
To ensure a proper fit between the different strips making up the module, a series of reliefs were envisaged on both sides of the strip. At first, they comprised a set of six "pivots" as relief on one side, and six "hollows" in the form of recesses on the other, designed in such a way as to allow a perfect fit between pieces. Initially, six vertical "elongations" with rounded edges were proposed.



Reliefs for positioning the tiles

Furthermore, the following conditions were taken into account when designing these reliefs (pivots and hollows) on each strip:

- Angle of *pivots and hollows*: following the die maker's recommendations, the most suitable geometry to achieve the fit between the front and back of the strips, and therefore between the modules, was with angles of 30º.

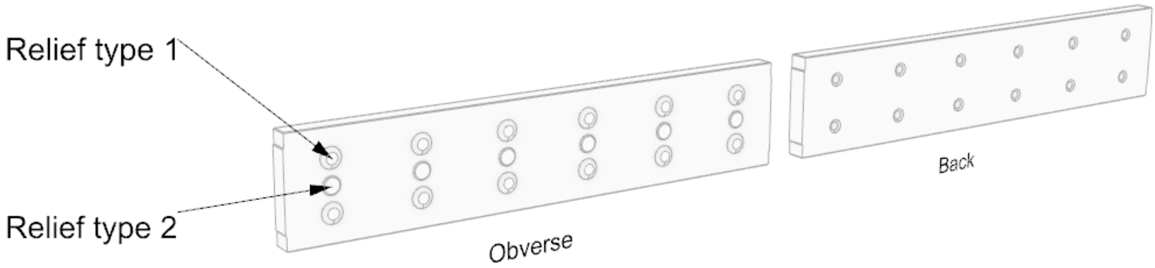


Angle of the reliefs

- *Pivots* no larger than 1.6 mm to avoid problems during the pressing process.
- Clearance between *pivot* and *hollow:* To allow proper fit between pieces, it was recommended that a gap be left to avoid contact between the surfaces at the bottom of the *hollow* and the top of the *pivot*. Assembly would those be by contact between the sides of the pivot and the hollow.

Positioning of the adhesive

Initially, it was decided to apply the adhesive to the top of the pivots, for two reasons: it allows the same thickness of adhesive to be maintained and, since there is a gap between the pivot and the hollow, that would allow the adhesive to be accommodated while keeping it "encapsulated" However, the first assembly tests showed that the presence of adhesive prevents the pivot and hollow from fitting properly if the adhesive is not deposited in exactly the right position or if too much adhesive is used for the available space. For that reason, the proposal now is for two types of relief: a Type 1 relief which enables the pieces to be positioned and the required 1 mm gap maintained, and a Type 2 relief, in which the adhesive is installed while its thickness continues to be controlled.

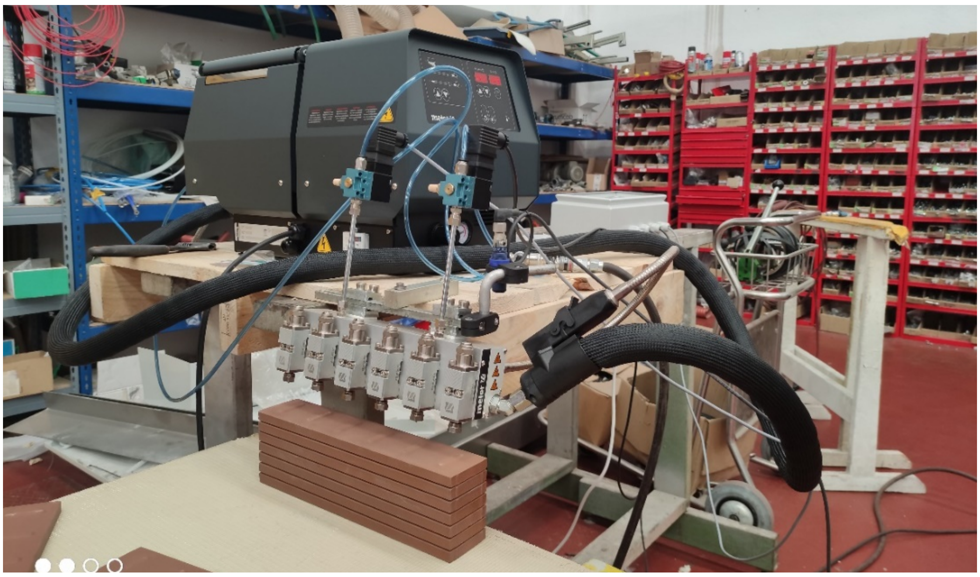


Change of relief positioning

TILE ASSEMBLY PROCESS

We are currently working with a 6-nozzle machine specialised in applying hotmelt adhesives, which allows the adhesive to be applied automatically. The tests carried out with this machine as well as the laboratory tests will indicate the most suitable choice of adhesive, the main requirements of which are as follows:

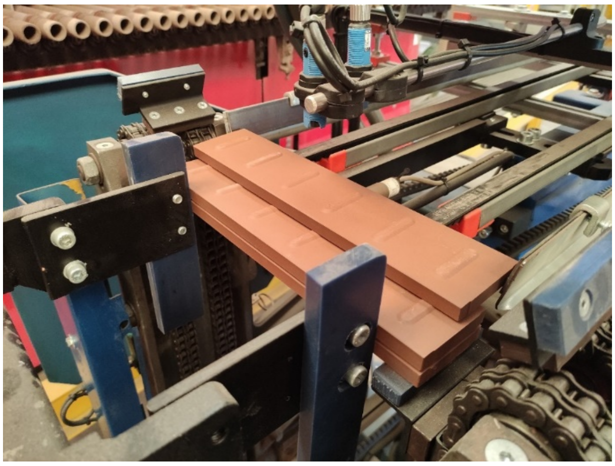
- Environmentally harmless once applied and cured.
- The machine does not require frequent maintenance and cleaning.
- Initial fast strength so that the piece can be handled as soon as the adhesive has been applied.
- Ability to resist solar radiation without detaching.
- Tensile adhesion strength after curing greater than or equal to 3 MPa.
- Resistant to contact with moisture or immersion in water.
- Frost resistant.



Machine for adhesive application

At the same time, a stacking device is being built so that, once the adhesive has been applied to the strips, the tiles can be stacked properly for stockpiling and packaging.

Dies in press



Stacker

CONCLUSIONS

This paper presents the partial results up to September 2023 of the DRAINKER project, which started in November 2022 and has a duration of 24 months. Specifically, the initial geometry of the ceramic pieces has been defined for a permeable urban paving module with the following characteristics:

- Modulated length and width dimensions to enable different configurations to be made.
- Sufficient edge to provide the required mechanical strength.
- NLT-327 permeability in the laboratory greater than 30,000 mm/h.
- Presence of reliefs and hollows to enable the strips to be automatically assembled by means of a stacker.