

USING THE IDEAS DIAGRAM METHOD TO DESIGN ABRASIVE WEAR TESTING EQUIPMENT

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ABSTRACT: The manufacture of concrete pavers may require the use of molds whose active elements are subject to abrasion wear. For this reason, the active elements are made of steels characterized by high wear resistance. The need to test the wear resistance of these steels required the design of equipment that would simulate, at least partially, the working conditions of the punches and active plates used in the manufacture of pavers. To identify an equipment solution that would meet the initial requirements, the ideas diagram method was used. The application of this method led to the obtaining of information on possible solutions for the desired equipment. By using certain evaluation criteria and an overall assessment, it was possible to gradually outline a solution for the equipment intended to allow tests to be carried out to determine the wear resistance of cylindrical steel specimens.
KEYWORDS: pavers manufacturing, molds, abrasive wear, testing equipment, ideas diagram method.

1. INTRODUCTION

In principle, *pavers* are blocks made of different materials (stone, brick, concrete, wood), usually of parallelepiped or prismatic shape, used to make paving for access roads, terraces, garden paths, street passages, squares, etc. Currently, the most widely used are concrete pavers.

The classification of pavers can take into account *the field of use* (industrial or residential applications), *the location* (interior or exterior surfaces of homes or various other categories of structures), *the thickness* or *traffic class* (there are pavers with thicknesses between 20 and 220 mm), *the quality of the active surfaces* (classic pavers or premium pavers), etc.

The main requirements that pavers must meet are those relating to physical and mechanical properties (abrasion resistance, resistance to compressive stresses, resistance to freeze-thaw cycles), dimensional stability, etc.), installation and operation possibilities (correct combination with other pavers, anti-slip characteristics, water drainage possibilities, resistance to the action of the environment or certain chemicals, ease of replacement, etc.) and, respectively, aesthetic requirements (the set of pavers could lead to a uniform image, sometimes it must contribute to the formation of images or symbols, allow their integration with the assemblies in which they are used, etc.).

Given that pavers are made in large series or mass, equipment is used in their manufacture, including molds that must correspond to the shapes, dimensions, and materials of the pavers.

If it considers the use of concrete in the manufacture of molds, it is obvious that the active elements of the molds will be subjected to abrasion wear processes, as a result of their operation. It is known that *abrasion* is a process in which abrasive particles with sharp edges, moving in contact with another object, can contribute to the removal of microchips from the material of the object with which the abrasive particles are in contact. As a result of abrasion wear, it is possible that the active elements of the mold (the punches and the active plate) can change their dimensions, which could affect the dimensional accuracy of the pavers manufactured with their help.

It has therefore become of interest to study the resistance to abrasion wear of the materials used in the active elements of the molds required in the pavers manufacturing processes. Thus, Cerlincă et al. conducted a study of the wear affecting the punches used in the manufacture of vibropressed pavers [1]. They observed that the wear of the punches' edges can lead to a change in the desired shape of the pavers' surfaces, through the appearance of a surplus of material, especially at the edges of the concrete pavers [Cerlinca et al., 2023].

The consultation of the specialized literature also highlights the attention paid by researchers to the abrasion wear of some categories of pavers or objects similar to pavers. Thus, Karaca et al. conducted a study aimed at obtaining information on the abrasion wear of some materials from the composition of stone floors concerning the value of the contact load [2]. It was found that the wear rate has a linear variation with the magnitude of the applied load.

To increase the resistance to abrasive wear and the bending resistance of the paver block, Kashiyani et al. proposed adding polypropylene fibers to the paver material (cement and dolomite powder) in the lower and upper areas of the block [3]. They highlighted the possibilities of improving the resistance to abrasive wear and the resistance to bending by adding polypropylene fibers in proportions of 0.3-0.4%.

An experimental research on the abrasion resistance of the concrete paving blocks and completed by a master's thesis, was carried out by Aslantaş [4]. He tested mixtures with different contents of white Portland cement. Testing of the blocks for compressive stress, splitting tensile strength, abrasion resistance, density, and water absorption was carried out after time intervals of 7, 14, and 28 days. The influence of the cement content on the mechanical properties of the block materials was highlighted.

A more extensive study of various research on the abrasion resistance of concrete surfaces was conducted by Warudkar and Elavenil [5]. They concluded that the abrasion resistance of concrete is influenced by aggregate type, compressive strength, cement content, water-cement ratio, and degree of hardening. It was appreciated that the mechanical properties of concrete can be significantly modified by the addition of silica fumes, fly ash, fibers, and latex.

On the other hand, it is known that in the activities of designing new or improved equipment, methods can be used that ensure a more efficient use of the designer's creativity. One such method is *the ideas diagram method*. In principle, the ideas diagram method involves a decomposition of the assembly to be designed into components for which it is necessary to identify different implementation options, and subsequently, by combining the component options, a multitude of possible solutions is reached. Among these solutions, it is possible to find new or improved variants compared to the known ones. The ideas diagram method was initially promoted by Professor Vitalie Belous, from the "Gheorghe Asachi" Technical University of Iași (Romania), and was later used by other researchers to solve a wide range of innovative design problems [6-12].

The objective of the research, whose results are presented in this article, was to identify an innovative equipment solution that would allow the wear testing of specimens made of the steel categories used in the molds for the manufacture of pavers. As such, a brief presentation of the principles of application of the ideas diagram method was first used. Subsequently, these principles were applied to outline a solution for the aforementioned equipment. Next, a first draft of an equipment variant considered to meet the initial requirements was made.

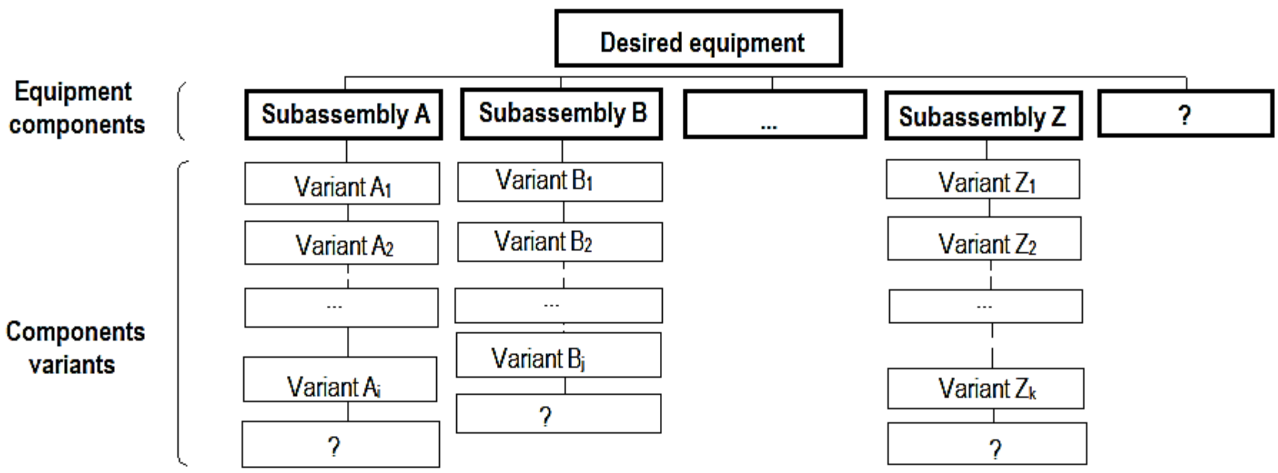

Figure 1. Basic representation of an ideas diagram

2. IDEAS DIAGRAM METHOD

As mentioned, the ideas diagram method is based on first identifying the different variants of the components of the desired equipment. Accepting the hypothesis that some combinations of these variants may present innovative aspects, it then resorts to identifying combinations that could be of interest from the point of view of efficiency and originality.

The name of the method comes from the use of a graphic representation in which it deals with a horizontal line under which, through vertical lines, the different components of the desired equipment are first inscribed, inside rectangles. These components are noted with capital letters of the Latin alphabet (A, B, C, etc.). Subsequently, their variants are inscribed under each of the components (Figure 1). The symbols of these variants of the subassemblies are differentiated from each other by adding numbers to the letters symbolizing the components of the equipment. For example, in the case of equipment A, there could be the variants of realization A1, A2, … Ai, etc. The number of variants of each subset may be different from the number of variants of the other subsets. Some researchers have suggested that including a summary sketch of the component inside each rectangle corresponding to a particular variant of a subassembly could help the designer to mentally manipulate this variant when faced with the problem of combining the variants [6-9].

It is necessary to emphasize that, as subassemblies, aspects that do not correspond to the usual meaning of the concept of subassemblies, but that allow differentiating some variants of the components, can also be introduced. For example, *the position of a certain component* (top, bottom, left, right, front, back), *color*, *a certain direction*, etc., could be used. If it is considered that such aspects can lead to different variants of the final assembly (variants among which there could be solutions superior to known solutions), it becomes useful to take them into account. For example, in the case of a motor vehicle or a means of river transport, the position of its engine (front, back) could be analyzed (and involved in the development of the ideas diagram).

It was appreciated [6-8] that, to another method of stimulating technical creativity, namely *the morphological matrix method*, *the ideas diagram method* should have a more open character, which should suggest to the innovative specialist the possibility that, in the future, other new subassemblies or their variants can be identified. For this purpose, it is recommended that a rectangle containing a question mark be inscribed in the horizontal line corresponding to the equipment components. Such a question mark could also be placed at the bottom of each column containing the variants of each equipment.

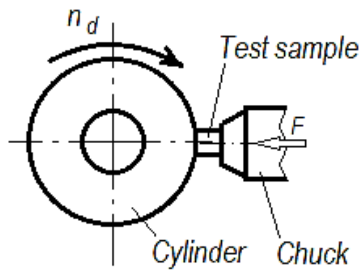

Figure 2. Selected work scheme for the study of abrasion resistance by the pin-on-disc method

3. USING THE IDEAS DIAGRAM METHOD TO IDENTIFY AN INNOVATIVE SOLUTION FOR WEAR TESTING EQUIPMENT

To apply the ideas diagram method to identify a solution for a wear testing equipment for steel specimens used to make the active components (punch and active plate) of a mold intended for the manufacture of pavers, it was first necessary to select the basic scheme of how the wear process is to be carried out. In this regard, pin-on-cylinder type work schemes are known (in which the specimen of the material to be tested is pressed onto a rotating cylinder with an abrasive outer surface), pin-on-disk (the rotating element is a disk and the specimen is pressed against the flat surface of the disk), pin-on-plate (the specimen is pressed onto a flat surface, relative to which it performs a certain movement), etc. From the literature review [13], a certain preference for the pin-on-cylinder type working scheme is noted, and this led to the consideration of such a working scheme in the case of the desired equipment (Figure 2). It can be seen that the adopted working scheme involves pressing a cylindrical specimen with a force of known magnitude F on the outer cylindrical working surface of a disk made of wear-resistant material and which rotates with a rotation speed n_d. A subsystem with a funnel is to direct an abrasive medium (in this case, a mixture of hard sand in water) into the space between the specimen and the disk. Since the disk is made of a hard and resistant material, as such, under the action of the abrasive material, it is expected that, within a certain time, the specimen will register a mass loss. If the length and mass of the specimen are measured before testing and the same measurements are made on the specimen after testing, the differences in the mass or length of the specimen will provide information on the wear resistance of the specimen material.

Next, by taking into account the information available in the literature, some of the main components of a pin-on-cylinder abrasive wear testing equipment were identified.

It was thus found that the main components or subassemblies of the desired equipment could be the following:

1. *The cylinder rotation subassembly* (subassembly A). For this subassembly, the following variants could be considered: A1 – subassembly in which the rotative cylinder could be mounted on the output shaft of the electric motor driving the cylinder into rotational motion; A2 – subassembly that will use a rotative cylinder support shaft placed parallel to the electric motor shaft, which will require the use of another transmission through cylindrical gears or belts; A3 – subassembly for transmitting movement from the electric motor shaft to the cylinder support shaft through a transmission that will include a bevel gear;
2. *The subassembly for locating and clamping the specimen* (subassembly B). As ways of materializing this subassembly, the following variants could be analyzed: B1 – vice with parallel jaws; B2 – bushing with a bore in which the specimen is fixed with a screw; B3 – chuck of the type used for locating and clamping drills; B4 – universal chuck of the type used on lathes;
3. *The subassembly necessary for pressing the specimen onto the cylindrical surface of the cylinder* (subassembly C). Some of the embodiments of this subassembly could be: C1 – Cable wound on rollers; at one end of the cable there is a plate with a weight of known size; C2 – spring for pressing the specimen; C3 – mechanism that uses an inclined plane, in which the lowering movement of a plate on which the weight of known size is placed is transformed into a pressing movement of the specimen onto the outer cylindrical working surface of the cylinder; C4 – subassembly with a hydraulic circuit that transmits the force generated by a weight of known size to a piston that will press the specimen onto the working surface of the cylinder;
4. *Subassembly/Subassemblies that ensure a certain relative position of the various components of the equipment to each other* (subassemblies D). The following materialization variants could be used in this regard: D1 – Columns on which the components can be moved using rack-and-pinion mechanisms, fixing in a certain position using screws; D2 – threaded columns, on which the components can be moved and immobilized in a certain position using nuts; D3 – articulated jack-type components;
5. *Subassembly for recirculating the abrasive mixture* (subassembly E). The variants identified for the materialization of this subassembly could be: E1 – without recirculating the abrasive medium; E2 - subassembly that will include a screw that will rotate inside a tubular part; E3 - a subassembly that will use a so-called continuous belt, equipped with cups that will move on two cylindrical rollers.

The application of the ideas diagram method could also take into account other subassemblies of the desired equipment or even other criteria that would lead to different solutions for the equipment (such as, for example, the way of placing the equipment components in different positions). For reasons of simplification of the description of the application of the ideas diagram method to identify an innovative solution for the desired equipment, the focus will be on the five subassemblies mentioned above.

A simplified graphic representation developed based on the five subassemblies taken into consideration can be seen in Figure 3.

At a later stage, an analysis of the different combinations of the subassemblies variants will be necessary, and the solution or solutions that present advantages from different points of view will be selected. The total number N_c of possible combinations of the different subassemblies' variants can be determined as a product of the variant numbers corresponding to each subassembly [6-8, 11]:

$$N_c = n_{vA} \cdot n_v B \cdot \ldots \cdot nv_M, \quad (1)$$

where n_{vA} is the number of variants of subset A, n_{vB} – the number of variants of subassembly B, n_{vM} – number of variants of the subassembly M.

Since in the case of the desired equipment, there are known n_{vA}=3 variants for subassembly A, n_{vB}=4 variants for subassembly B, n_{vC}=4 variants for subassembly C, n_{vD}=3 variants for subassembly D,

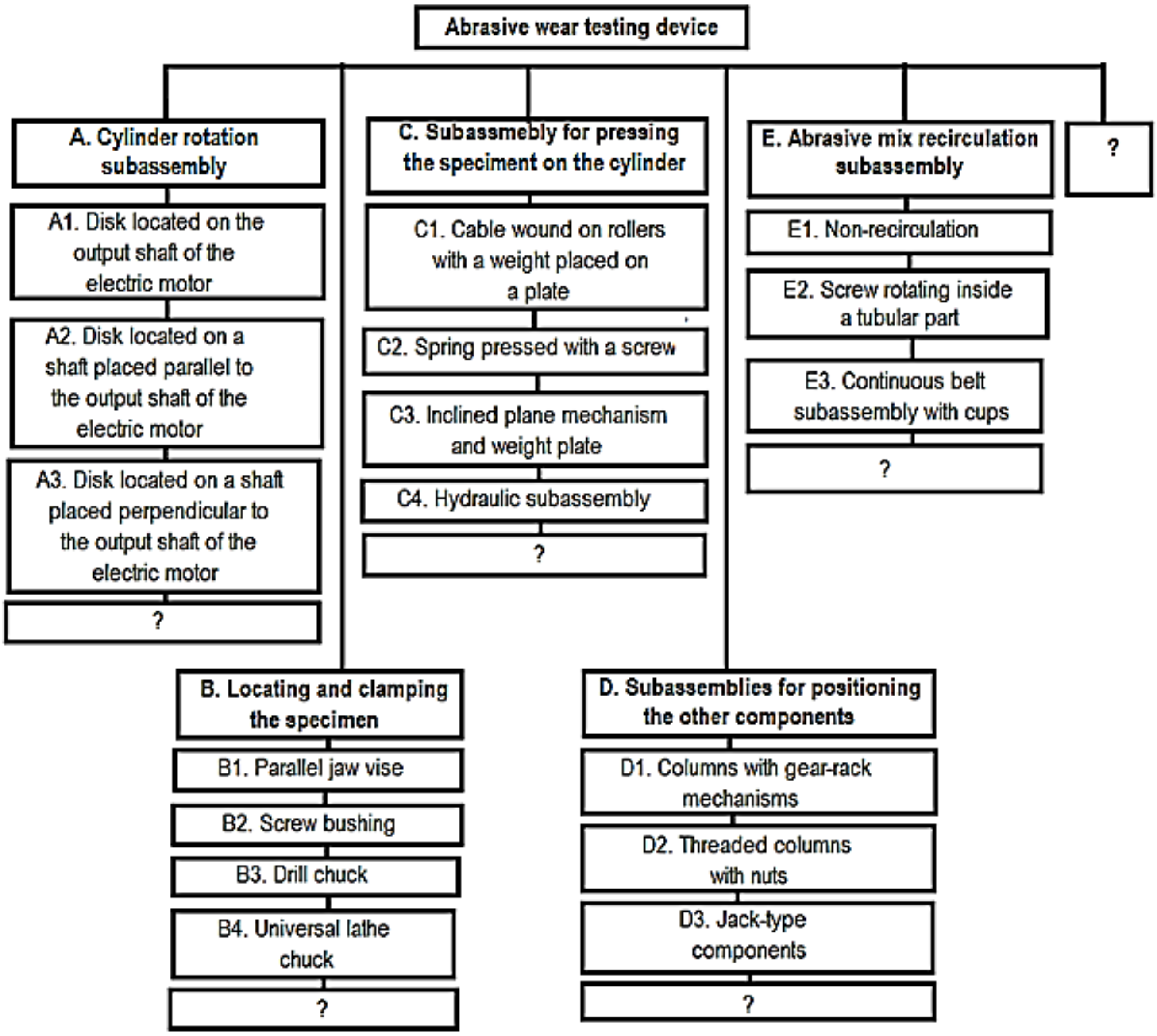

Figure 3. Ideas diagram valid for the equipment intended to study the wear resistance of a steel specimen used in the manufacture of punches and the active plate of molds for the manufacture of pavers

and n_{vE}=2 variants for subassembly E, the total number of possible combinations will be:

$$N_c=3\cdot4\cdot4\cdot3\cdot3=432 \text{ combinations.} \quad (2)$$

An analysis of all 432 possible combinations of the variants of the 5 subassemblies considered would be very difficult, due to the large number of these combinations. Selecting the most suitable combination, or at least narrowing down the number of combinations so that only a small number of combinations can be analyzed in more detail, can be done in several ways. A first usable variant in this regard could be an operational global evaluation, in which the professional experience of the designer plays an important role. This variant has the advantage of a short application time, but does not offer the certainty of choosing the most suitable solutions for the targeted equipment.

The selection can also be carried out by using methods that aim to reduce the number of combinations that will later be analyzed in more detail, by methods such as the method of comparing pairs of combinations, methods from the field of value analysis, etc. Some of the methods capable of helping the designer reduce the number of variants susceptible to more detailed analysis are the sequential-selective selection method, the division method by sub-morphologies, the selection method by simple randomization, by weighted randomization, or by similarity, etc.

4. PROPOSED SOLUTION

For operational reasons, it was preferred to apply a global assessment to identify a suitable solution for the device intended to allow experimental research on the abrasion resistance of certain steel specimens. In evaluating the different combinations, criteria such as the possibilities of in-house manufacturing of some components, the ease of purchasing other components, the simpler use and maintenance of the equipment, etc., were taken into account. Under these conditions, it was considered that the most suitable option could be the one to which the symbol A1B3C3D2E1 corresponds.

Following the aforementioned, such a solution involves the use of a subassembly A of type A1, in which the specimen could be mounted on the output shaft of the electric motor driving the specimen in rotational motion, a subassembly B of type B3 – a chuck of the type used to locate and clamp drills, a subassembly C of type C3 – a mechanism that uses an inclined plane, in which the lowering movement of a plate on which the weight of known size is placed is transformed into a pressing movement of the specimen on the outer cylindrical working surface of the cylinder, a subassembly D of type D2 – threaded columns, on which the components can be moved and immobilized in a certain position with the help of nuts, and, respectively, a subassembly E of type E2 – a subassembly that will include a screw that will rotate inside a tubular part.

A schematic representation of the designed equipment can be seen in Figure 4. The equipment uses a weight of a predetermined size placed on a plate supported by a vertical rod. In the lower zone of the vertical rod to whose lower area a part with an inclined plane at an angle of 45 ° was attached. When the vertical rod is lowered, the flat surface inclined at 45 ° of the part will press on a roller that can rotate on a shaft belonging to the subsystem for locating and clamping the specimen, made of the material to be tested for wear by abrasive erosion.

The specimen is pressed as a result of the action exerted by a weight placed on a plate on the outer cylindrical surface of a cylinder made of very hard and resistant material, so as such, to wear by abrasive erosion. The disk is driven into rotation by a direct current electric motor, placed on a plate that can move and be fixed in an appropriate position on a threaded column.

The abrasive granules arrive from a funnel in the area between the rotating disc and the specimen, some of them, that is, those that arrive between the cylinder and the specimen, causing a process of abrasive erosion of the specimen material.

The abrasive grains that have passed through the space between the cylinder and the specimen, as well as those that have not effectively participated in the wear process, end up in a vat, whose inclined bottom causes the abrasive grains to accumulate in the lower area of the vat. A subsystem containing a screw located inside a cylinder will take over the abrasive grains and return them to the funnel. The screw is driven into rotation by an additional electric motor, located using a bracelet-type subsystem on a plate that can be moved for the correct positioning of the screw along the same threaded column.

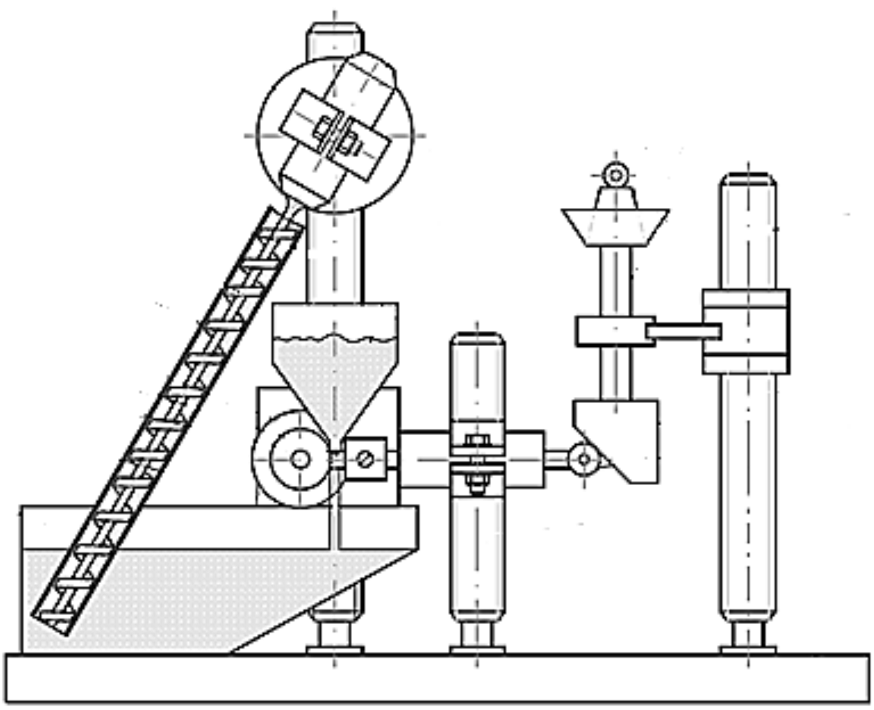

Figure 4. Schematic representation of the proposed device for experimental research of the wear process in the case of steel specimens used to make the active elements of the molds for the manufacture of pavers

Another threaded column allows the appropriate positioning of the weight support subsystem located on the plate, along a vertical direction.

A third threaded column was provided for the appropriate positioning of the subsystem for locating and clamping the specimen.

The three threaded columns are fixed to the base plate of the equipment.

Using such equipment, it is possible to study the influence that the input factors in the abrasive erosion process, such as the nature of the sample material, the pressing force of the sample on the surface of the rotating cylinder, the composition and characteristics of the mixture containing the abrasive grains, etc., exert on the intensity of the abrasive erosion process.

5. CONCLUSIONS

The manufacture of pavers involves the use of molds whose active elements are subjected to abrasion wear processes. The identification of the most suitable materials for the punches and active plates used in the manufacture of paving stones requires the development of research that allows the evaluation of the abrasion wear resistance of certain categories of steels. To identify equipment with which it would be possible to test the abrasive wear of steel specimens, the ideas diagram method was used. The application of this method facilitated the gradual outline of a solution for the equipment intended for testing the abrasion wear resistance. In the future, it is intended to materialize the equipment and use it to determine the influence that different factors exert on the abrasive wear resistance of cylindrical specimens made of certain steels.

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