INFLUENCE FACTORS AND SPECIFIC REQUIREMENTS FOR RESEARCH ON THE ABRASIVE EROSION WEAR PROCESS

Ștefan Jureschi[1], Margareta Coteață[2], Irina Beșliu-Băncescu[3], Ioan Surugiu[4], Mihai Boca[5], Roxana Gabriela Hobjâlă[6], Vlada Țisari[7] and Laurențiu Slatineanu[8]

[1] *"Gheorghe Asachi" Technical University of Iaşi, Romania, e-mail: stefan.jureschi@student.tuiasi.ro.*
[2] *" Gheorghe Asachi" Technical University of Iaşi, Romania, margareta.coteata@academic.tuiasi.ro.*
[3] *"Ştefan cel Mare" University of Suceava, Romania, e-mail: irina.besliu@usm.ro.*
[4] *"Gheorghe Asachi" Technical University of Iaşi, Romania, e-mail: ioan.surugiu@student.tuiasi.ro*
[5] *"Gheorghe Asachi" Technical University of Iaşi, Romania, e-mail: mihai.boca@academic.tuiasi.ro*
[6] *"Gheorghe Asachi" Technical University of Iaşi, Romania, e-mail: roxana.gabriela.hobjala@student.tuiasi.ro.*
[7] *"Gheorghe Asachi" Technical University of Iaşi, Romania, e-mail: vlada.tisari@student.tuiasi.ro.*
[8] *" Gheorghe Asachi" Technical University of Iaşi, Romania, laurentiu.slatineanu@academic.tuiasi.ro.*

Abstract: *The active components of the molds used for the manufacture of vibropressed concrete pavers are subject to abrasive erosion processes. These active components are usually made of manganese steels. For the experimental research of the abrasive erosion process of manganese steel test samples, it was necessary to design equipment that meets the requirements of abrasive erosion testing. The systemic analysis method was used to highlight the factors capable of exerting influence on some output parameters of the abrasive erosion process. Some principles of axiomatic design allowed establishing correlations between the functional requirements and the corresponding design parameters of the equipment intended for the experimental research of the abrasive erosion process by using the pin-on-ring method. In this way, a device adaptable to a universal lathe was designed, which provides conditions for researching the influence exerted by some factors on the dimensions of the crater generated in the manganese steel test sample by abrasive erosion.*

Keywords: *abrasive erosion, systemic analysis, influence factors, pin-on-ring, device adaptable to a universal lathe.*

1. Introduction

Pavers are individual parts used to create durable and attractive walkways, such as proper walkways, sidewalks, and patios. The main materials used to make pavers are concrete, natural stone, and clay (brick). The shapes and sizes of pavers are determined so that they can be interconnected and provide a certain flexibility in the layout, compared, for example, to the use of a cast concrete slab.

One of the technologies for making pavers is vibropressing. Basically, the mixture of substances corresponding to a certain category of concrete is pressed or vibropressed into molds of appropriate shapes and sizes. The service life of the active elements of these molds (active punches and plates) depends primarily on the wear resistance of the materials used to make them.

High resistance to erosion wear is therefore one of the main functional requirements for the materials used to make the punches and active plates of the molds for making pavers. Such materials are, for example, wear-resistant manganese steels, such as 16MnCr5 and 20MnCr5.

It was natural for researchers to be interested in studying the wear behavior of steels used for the manufacture of vibropressed concrete elements.

Thus, Baykara and Atik investigated the wear of 16MnCr5 steel samples subjected to carburizing operations at 900 ° C for 3.5 hours and presenting, as such, a carburized layer with a thickness of 1.04 mm [Baykara, 2025]. They assessed that by ensuring a higher wear resistance of 16MnCr5 steel parts, it is possible to reduce the consumption of materials and the costs for the maintenance and repair of parts made of this steel.

In a paper published in 2014, Tarasyuk et al. presented the results of research on the abrasive wear of the surfaces of 20MnCr5 steel test samples previously treated by the welding micro-jet method [Tarasyuk, 2014]. They highlighted the fact that the intensity of the abrasive wear process can be reduced by about 20% as a result of the applied treatment. Subsequently, Tarasyuk et al. researched the abrasive wear resistance of 20MnCr5 steel test samples previously treated by carburizing, boronizing, and several diffusion chromium plating methods [Tarasyuk, 2016]. It was found that the most suitable in terms of abrasive wear resistance were the test samples previously treated by boronizing or carburizing.

Some results on the mechanical properties and wear resistance of some categories of steels, including 20MnCr5 steel, were investigated by Krupicz et al. [Krupicz, 2016]. To evaluate wear resistance, they used a steady stream of solid particles.

The abrasion and corrosion resistance of the high-temperature carburizing steel 20MnCr5 was investigated by He et al. [He, 2023]. They concluded that by microalloying with niobium, it is possible to increase the resistance to dry sliding wear.

To study the wear resistance of some steels, including 16MnCr5 steel, Ťavodová et al. used an experimental method based on pressing a rotating rubber disc onto the test sample [Ťavodová, 2024]. In this way, it became possible to recommend certain materials to ensure better wear behavior of parts made of such materials. The abrasive wear research method has also been used by other researchers [Falat, 2019].

Some tribological properties of 20MnCr5 steel test samples made by direct metal laser sintering were investigated by Żaba et al. [Żaba, 2025]. They concluded that tools containing inserts or working layers manufactured by 3D printing can prove effective for forming sheets of 321 steel and Inconel 625.

The results of experimental linear-orthogonal machining were used by Troß et al. to adapt the Johnson-Cook material model to the case of 20MnCr5 case-hardened steel without thermochemical treatment [Troß, 2023].

The Soviet standard GOST 23.208-79 described an abrasive erosion test method in which a rotating rubber disc is pressed with a known force onto a fixed test sample [GOST, 1979]. The space between the rotating disc and the test sample is filled with abrasive grains in a funnel-shaped container. The study of the crater dimensions generated by the abrasive grains after a certain period of the abrasive process should provide information on the resistance to abrasive erosion of the test sample material.

The research, the results of which are presented in this article, aimed to identify the factors capable of influencing the wear resistance of some steels used for the active elements of the molds applied in the manufacture of pavers by vibropressing. For this purpose, an analysis of the aforementioned influencing factors was first used, to subsequently formulate the requirements for equipment usable for the study of the resistance to abrasive erosion of some manganese steel test samples.

2. Selecting a work scheme for researching an abrasive erosion wear process

The study of the specialized literature has highlighted the existence of several groups of

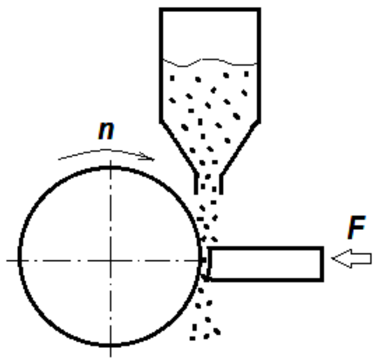

Figure 1: *Scheme adopted for abrasive erosion testing of manganese steel test samples (n – disc rotation speed, F – force of pressing the test sample on the disc)*

methods and procedures that allow the study of the abrasive wear behavior of metallic and non-metallic materials. By taking into account the specific working schemes of these procedures, it was found that there are pin-on-disc, pin-on-cylinder, pin-on-ring, etc. methods [Baykara, 2025; GOST, 1979; He, 2023; Krupicz, 2016; Ťavodová, 2024; Żaba, 2025; Zavos, 2015]. In the case of these methods, test samples of the material to be investigated are pressed with a force of known magnitude on solid bodies made of wear-resistant materials, with abrasive grains being introduced between the working surface of the test sample and the moving part.

Another group of methods uses a rotating body pressed with a force of known magnitude on the flat working surface of a test sample. In the case of these methods, the equipment seems to be simpler and it is also possible to investigate some dimensional characteristics of the craters generated by wear.

Taking into account the information identified in the literature and relating to the input factors and output parameters of the abrasive erosion process led to the formulation of an option according to which the abrasive erosion testing scheme could involve pressing a test sample of the steel to be studied, of parallelepiped or cylindrical shape, onto the surface of a disc or ring of hard material and in rotational motion (Fig. 1). Such a scheme is known in the literature as "pin-on-ring".

3. Output parameters and input factors in the abrasive erosion wear process exclusively in granular media

In the case of test samples pressed onto the surfaces of rotating bodies, the evaluation of the wear behavior of materials through abrasive erosion can be carried out by determining the decrease in mass or length of the test sample at predetermined time intervals, as a result of wear processes.

For the group of processes that involve pressing rotating discs on the test sample of the investigated material, as previously mentioned, some *output parameters* of the abrasive erosion process can be the geometry of the test sample surfaces resulting from the test and the dimensions of the crushed grains.

The main *input factors* or groups of input factors in the wear process can be considered the following;

1. The physical and mechanical properties of the test sample material;
2. The physical and mechanical properties of the counterpart material;
3. The presence, physical and mechanical properties, and dimensions of abrasive grains;
4. The type and speed of relative movement between the test sample and the counter piece;
5. The magnitude of the pressing force between the test sample and the counterpart;
6. The lubricating properties of the medium containing abrasive grains;
7. The rigidity of the testing equipment.

4. Using systemic analysis to highlight correlations between input factors and output parameters of the abrasive erosion wear process

Systemic analysis is a method that considers the process or equipment under investigation as a system. This means that the process or object/equipment under investigation (part or assembly) must have input factors, the variation of which can affect the values of the output parameters of the system. If only those factors whose values can be established by the researcher are taken into account as input factors, it is necessary to mention that there are also *disturbing factors*, the values of which can influence the values of the output parameters, but which cannot be established/adjusted by the researcher before the experimental test is carried out.

In Figure 2, a graphic representation corresponding to the application of some principles of systemic analysis to the research process of the behavior of materials under abrasive wear can be observed

5. Requirements for equipment intended for studying the abrasive erosion process

By taking into account the selected abrasive erosion testing scheme (Fig. 1), the problem of designing equipment that would allow the materialization of that scheme was raised. A first step that must be taken in this regard is the formulation of the functional requirements that such equipment must meet.

An interesting and efficient way of formulating the functional requirements corresponding to an equipment that needs to be designed is the one proposed by *axiomatic design* [Dodun, 2022; Slătineanu, 2020; Suh, 2001]. It is known that axiomatic design is based on two axioms. The two axioms are the axiom of independence of functional requirements and the axiom of minimum information (the axiom according to which it is required that, when there are several alternatives, the alternative that requires the least information be selected).

After the functional requirements are formulated, the design parameters corresponding to these requirements will be mentioned, which are, in fact, the solutions capable of contributing to the fulfillment of each functional requirement. There may be one or more initial functional requirements, called *zero-order functional requirements*. The answers to the functional requirements will allow the gradual identification of all the components of the desired equipment.

It will be considered that the idea of using

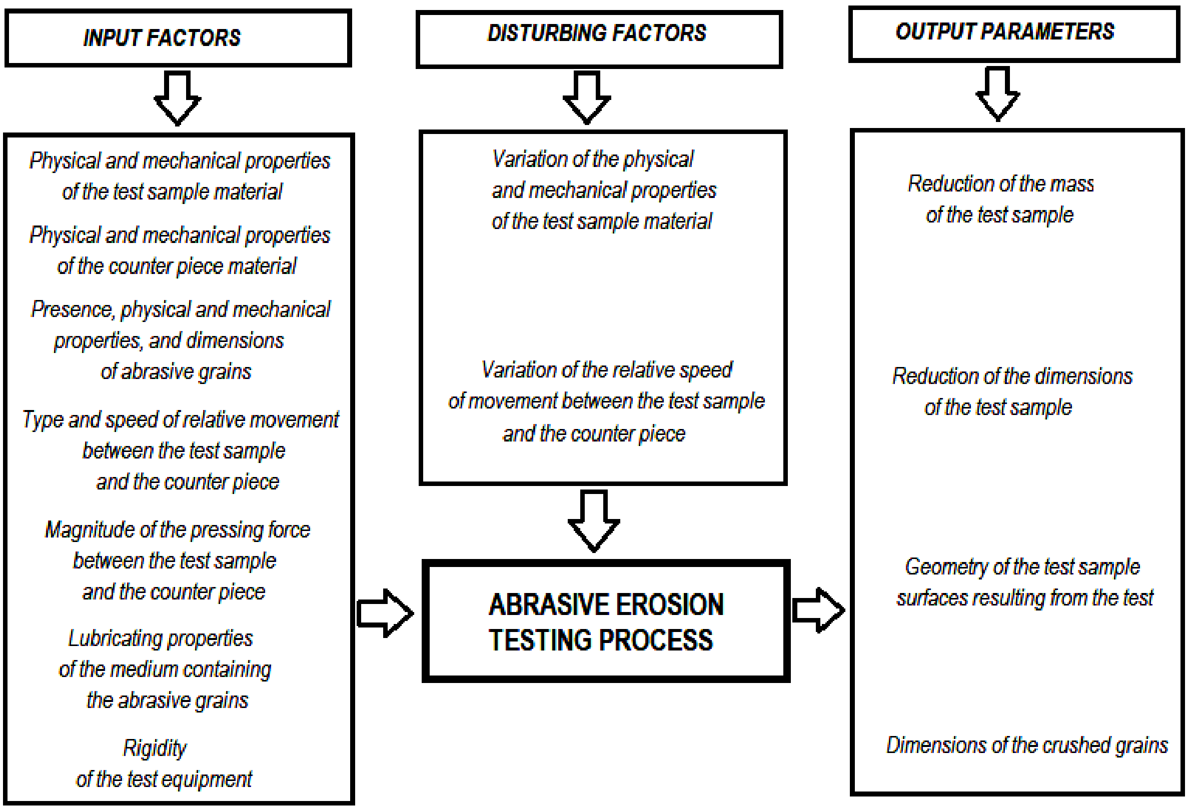

Figure 2: *Graphical representation resulting from the use of systemic analysis to highlight the influence exerted by some input factors in the abrasive erosion process on the values of an output parameter from this process.*

an abrasive erosion testing scheme based on the pin-on-ring method has been reached, a method that could be applied on a universal lathe. The idea of using a universal lathe was taken into account, knowing the wide range of spindle speeds that can be materialized, including by the hard material ring.

In the case of equipment intended for abrasive erosion testing of manganese steel test samples used for the active elements in the molds applied to manufacture vibropressed concrete pavers, as *a zero-order requirement*, it can be considered:

FR0: Design an equipment that allows abrasive erosion tests to be performed on steel test samples.

The zero-order design parameter corresponding to this zero-order functional requirement will be the desired equipment itself:

DP0: Equipment for performing abrasive erosion tests on steel test samples.

Next, it is necessary to decompose the zero-order functional requirement into several *first-order functional requirements*. These first-order functional requirements could be the following:

FR1: Provide a subsystem for locating and clamping the abrasive erosion-resistant disc;

FR2: Provide a subsystem that allows the abrasive erosion-resistant disc to rotate around its axis;

FR3: Establish the shape and dimensions of the steel test sample whose resistance to abrasive erosion is to be investigated;

FR4: Provide a way to locate and clamp the test sample;

FR5: Provide a subsystem that allows the test sample locating and clamping device to move towards the hard material disc, along a horizontal direction;

FR6: Provide a subsystem that allows the generation of the force necessary to press the test sample onto the abrasive erosion-resistant

Table 1: *Matrix for highlighting first-order functional requirements and first-order design parameters and the correlations between them.*

Line no. 1	Design parameters / Functional requirements		Design parameters											
2			Zero-order design parameter											
3			DP0: Equipment for studying the abrasive erosion resistance of manganese steels											
4			First-order design parameters											
5			DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	DP11	DP 12
Column no. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7	Zero-order functional requirement	First-order functional require-ments	Highlighting the first-order design parameters DPi corresponding to the first-order functional requirements FRi											
8	Design equipment for studying the abrasive erosion resistance of manganese steels	FR1	X											
		FR2		X										
		FR3			X									
		FR4				X								
		FR5					X							
		FR6						X						
		FR7			X	X	X		X					
		FR8							X	X				
		FR9									X			
		FR10										X		
		FR11											X	
		FR12	X	X	X	X	X	X	X	X	X	X	X	X

disc;

FR7: Provide a subsystem for connecting the subsystems for generating force and moving the device for locating and clamping the test sample to the hard material disc;

FR8: Provide a subsystem for supporting the subassemblies involved in pressing the test sample onto the abrasive erosion-resistant material disc;

FR9: Provide the locating and clamping of the subsystem for supporting the various components on the lathe;

FR10: Provide the presence of an abrasive medium in the space between the test sample and the hard material disc;

FR11: Provide a subsystem for storing and accessing the abrasive medium in the space between the test sample and the abrasive erosion-resistant material disc;

FR12: Ensure the existence of a subsystem to support the storage and access subsystem of the abrasive medium in the space between the test sample and the abrasive erosion-resistant disc.

The design parameters corresponding to these functional requirements could be:

DP1: Mandrel on which the abrasive erosion-resistant disc can be located and clamped using a nut;

DP2: Universal lathe chuck and a rotating center located in the tailstock;

DP3: Parallelepiped test sample, with dimensions of 19x10x20 mm^3;

DP4: Bushing having a square cross-section hole;

DP5: Roller guide carriage;

DP6: Counterweight subsystem;

DP7: Metal plate;

DP8: Bar attached to the metal plate;

DP9: Tool holder support;

DP10: Abrasive grains;

DP11: Adjustable opening funnel;

DP12: Universal lathe.

The information regarding the functional requirements and the design parameters mentioned above has been included in a synthetic form in Table 1. The functional requirements have been highlighted in column 3, and the design parameters along line 5 of the table. The existence of connections between the functional requirements and the design parameters has been highlighted by entering “X” symbols in some of the table locations.

It can be seen that all the “X” symbols have been placed along and respectively below the descending diagonal in Table 1. According to some principles of axiomatic design [Suh, 1990; Slătineanu, 2020], such a design is considered to be *an uncoupled design*, and it is considered acceptable. It is worth noting that an optimal design would correspond to the situation in which all the “X” symbols would have been arranged along the descending diagonal in the table.

The functional requirements breakdown could continue by breaking down each first-order functional requirement into *second-order functional requirements*, and so on, until the existence of each component of the device can be justified.

6. Proposed testing scheme

A variant of the materialization of the equipment designed by taking into account the functional requirements and the design parameters mentioned above is the one presented, simplified in Figure 3. As mentioned above, a device was designed that could be placed on a universal lathe. Such a solution allows the use of peripheral speeds of the disc made of abrasive erosion-resistant material with values between wide limits, making it possible, in this way, to also research the influence exerted by the peripheral speed of the disc on the dimensions of the crater generated on the test sample made of the investigated steel.

The disc of a certain material (intending to use a metal carbide insert in the shape of a disc with a central hole) will be located and clamped with a nut on a mandrel positioned, in turn, in the universal chuck of the lathe and, respectively, in a rotating center mounted in the quill of the mobile headstock. The parallelepiped-shaped test sample made of manganese steel will be located and clamped

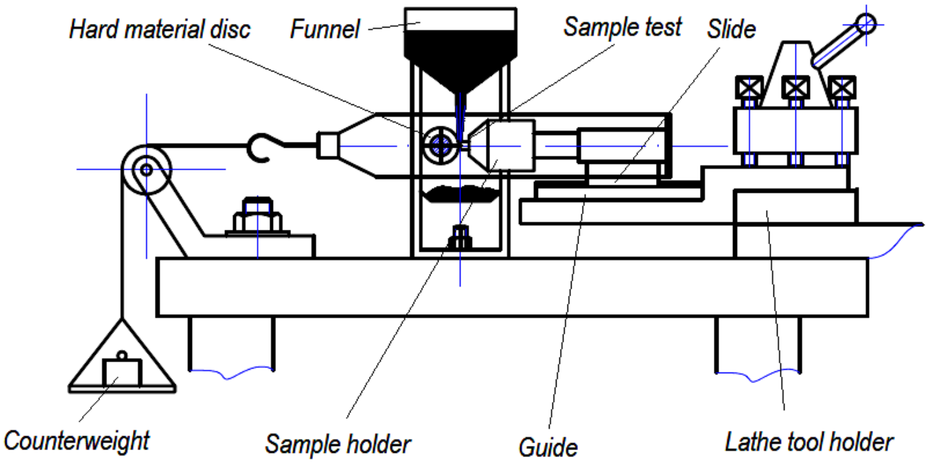

Figure 3: *Simplified representation of the proposed device for experimental research of the abrasive erosion process in the case of manganese steel test samples.*

inside a hole with a square cross-section in a test sample holder bushing.

The bushing will be integral with a part that will be placed on a sled that can move along a horizontal direction on a guide, by means of rollers. It was opted for pressing the test sample on the outer cylindrical surface of the hard material disc by means of a subsystem with a counterweight.

The subassembly for supporting and pressing the test sample onto the hard material disc will be mounted in one of the 4 slots of the universal lathe tool holder.

The abrasive grains will be stored in a conical container, from where they will reach, by moving under the action of their own weight, the area between the disc and the test sample. As a result of penetrating this space and rotating the disc, it is expected that the grains will cause a crater to appear on the flat surface of the test sample, thus providing information on the resistance to abrasive erosion of the manganese steel from which the test sample is made.

As input factors in the abrasive erosion process whose values can be modified, the peripheral speed of the hard material disc, the force and therefore the pressure exerted by the test sample on the hard material disc, the duration of the testing process, the dimensions, shape, and nature of the abrasive grain material, etc., are mentioned.

7. Conclusions

The study of the specialized literature highlighted the existence of an interest of researchers in studying the resistance to abrasive erosion of the steels used to make the active elements of the molds necessary in the process of manufacturing the pavers. Among the abrasive erosion testing schemes presented in the specialized literature, a pin-on-ring type scheme was preferred. The application of the systemic analysis method allowed the highlighting of factors and groups of factors capable of exerting influence on the dimensions of the crater generated by the abrasive grains on the surface of the test sample. The use of some principles of axiomatic design facilitated the gradual outlining of solutions for the structure of a device adaptable to a universal lathe, and which would allow the development of experimental research on the resistance to abrasive erosion of some manganese steels. In the future, it is considered possible to manufacture such a device and, respectively, carry out experimental research in the mentioned direction.

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