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DEVELOPMENT OF AN INNOVATIVE TECHNICAL SOLUTION FOR THE APPLICATION OF SEGMENTAL MANAGAN INSERTS ON THE WEAR SURFACE OF THE CLAMP OF THE TAMPING RAILWAY MACHINES

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Abstract:
Research in this paper is focused on defining the appropriate methodology of integrated product development in the process of constructing and practical application of replaceable segments that are installed on the working surface of the rail construction tamping machine. The research presents an innovative solution of segmental cast inserts made of special alloyed steel with manganese as the alloying element. The specially designed segment of the clamp is a spare part that requires timely replacement to ensure optimal operation of the machine and more extended exploitation. In the paper, the innovative solution was compared with the traditional maintenance procedure by hardfacing a layer on the worn surface of the clamp. The innovativeness of the proposed technological procedure for the maintenance of clamps is reflected in the better reliability, i.e. the extension of the shelf life by up to 4.5 times and the reduction of maintenance by 40.62 times compared to the traditional method of reparative hardfacing. Efficiency, as a key factor in maintenance, is reflected in the fact that, with an inventive solution, the replacement of worn segmental inserts can be done in the field without the need to demobilize the tamping machine and send it to the workshop.

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1. INTRODUCTION

The main characteristics of rail transport are the high economy and the price of cargo transport, which ranks right behind sea transport [1]. These benefits have contributed to the growing demand for rail transport yearly. The increase in traffic intensity leads to a greater load and speed of vehicles, which ultimately results in the rapid deterioration of this infrastructure [2,3]. Maintaining the infrastructure of the railway system in good condition is a very complex process, which depends on the safety of passengers and goods, as well as the efficiency and reliability of the entire logistics system [4-6]. Due to the lack of maintenance of the railway infrastructure, catastrophic events can occur, such as train derailment, broken rails, etc. [7]. Those mentioned above can have negative consequences for people and the environment, especially when transporting dangerous cargo, such as toxic, explosive, radioactive, and similar. The growth of these dangerous cargoes shows constant growth; for example, only China itself has a growth of 36% annually [8].

In practice, efficient and timely maintenance (preventive, corrective and predictive) of railway infrastructure requires adequate resource allocation for different operations, which causes

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numerous practical and operational problems [9,10].

The development of railway technical systems requires the initiation of numerous research studies and the application of new maintenance methodologies, all with the aim of achieving a satisfactory quality of railway elements and equipment as quickly, qualitatively, reliably and efficiently as possible [11]. The primary task for the development of new innovative technological processes for the restoration of damaged objects is to define the appropriate working parameters at which the output parameters would have optimal values [12].

2. TECHNOLOGICAL PROCESS OF BUILDING A STONE CURTAIN UNDER THRESHOLDS

Railway sleepers are parts of the track system structure in railway traffic [13], placed between the railway track and the ballast carrier [14]. The basic function of sleepers is to ensure the stability of the rail network in the vertical and horizontal planes [15], that is, to absorb the pressure from the rails and transfer it to the ballast layer [16]. The number of sleepers usually ranges from 1000 to 2000 pieces per kilometer of track, depending on the type of traffic, train speed, required load, curves, etc. [17].

When laying tracks with sleepers (lifting and transferring) directly under the sleepers, a cavity is formed; this must be filled with stone and compacted during subsequent shoring. The backfilling process involves additional movement of individual sleepers to transport the stone from the space between the sleepers to the space below the sleeper. Hydro-squeezing ensures the necessary compaction of the stone. Then, with the clamps, the stone is compacted with an increased impact-vibration process, a beneficial technological action for achieving the most robust possible foundation under the sleepe, Fig.1.

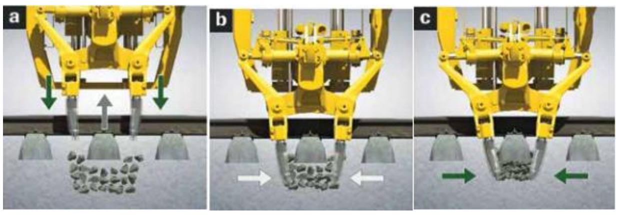

Fig. 1. The technological process of tamping the stone with the tool clamps a) the sleeper is raised, and a space is created under the sleeper, b) the space created by raising the sleeper is filled by squeezing, and c) the stone is compacted by the vibration process [18]

The technological process of tamping the stone under the sleepers takes place in several stages, depending on the action of the aggregate clamps on the stone (Fig. 1): lifting/handling and penetration, filling and compaction [19]. Fig. 2 shows the stone tamping machine with executive tool clamps, used to rehabilitate railways in the Railways of the Republika Srpska in Bosnia and Herzegovina.

Fig. 2. Tamping hydraulic machine with executive tool clamps

The degree of abrasive damage to the clamps with the coated working surface is one of the limiting factors for the quality execution of the technological process of stone tamping in a specific time. This was the main reason for the development of a new innovative concept of maintaining the wear surface of the clamps, which will provide greater resistance to wear, longer shelf life, a simple replacement procedure in the field, reduced maintenance costs, and a visible economic effect.

3. MATERIALS AND METHODS

The research was carried out on the special-purpose tamping railway machine, which is used for the maintenance of railways and railway facilities. The technological function of the tamper is to underlay the stone under the sleepers of tracks and switches, with the possibility of tamping one or more sleepers at once. The executive tools of the stone tampers are clamps. Clamps are installed on the tamping hydraulic machine, and in one set, depending on the tamping machine series, 16 or 32 clamps are installed. Fig. 3 shows the tamping railway machine (manufactured by Plasser & Theurer) with 32 clamps. These machines are owned by all railway infrastructure companies in the number depending on their own needs. All the research in the paper was carried out using the equipment and machines of the Railways of the Republika Srpska (Bosnia and Herzegovina). The total number of tamping machines working in the Railways of the Republika Srpska is currently 12 machines.

The research aimed to develop an innovative technical solution for applying segmental manganese inserts to the clamp's wear surface. The main features of the presented technical solution are its great applicability, work efficiency, time savings, and economic use.

Research in natural conditions was carried out on the tamping machine, which exploits 16 clamps (8 installed with weld from worn surfaces and 8 with replaceable segmental manganese inserts). In the research, the wear parameters of both variants of parts were observed by precise measurement. These measurements were performed on the equipment before installation and after 100 hours of effective machine operation. Also, the material costs in the maintenance of the railway construction tamping machine with installed 32 clamps in 12 months or for effectively spent 400 work hours were also investigated.

Fig. 3. Duomatic tamping railway maintenance machine

3.1 Tool for Tamping the Stone - Clamp

Tamping clamps, in direct contact with the stone, endure high-intensity abrasive wear and strong impacts. The severity of their wear is a function of the mechanical properties of the clamp material and the stone's characteristics. The wear of the contact surface of the clamps occurs through the mechanism of abrasive wear, known as the open type, a testament to their resilience under challenging conditions.

Clamps (Fig. 4) are forged machine elements with specific designs and shapes. They are produced by a very demanding technological process, exclusively by matrix forging, made of alloy steel (42CrMo4). Also, in the work process, they are exposed to combined vibrating loads, so the structurally defined demanding mechanical characteristics that are achieved by heat treatment are shown in Table 1. Boundary vibration stresses in the exploitation of clamps are shown in Table 2.

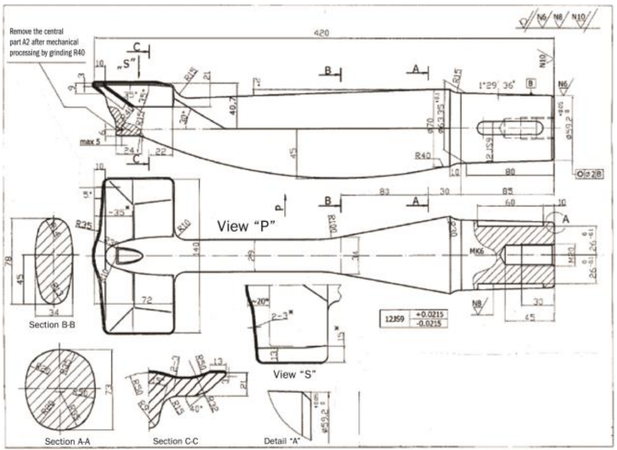

Fig. 4. Design of the clamp of the tamping railway construction machine [20]

Table 1. Mechanical characteristics of clamp material after heat treatment [21]

Yield strength R_e (N/mm^2) min.	Tensile strength R_m (N/mm^2)	Hardness HB	Elongation A (%) min.	Contraction Z (%) min.	Tenacity (J) min.
635	880 ÷ 1080	280 ÷ 310	12	50	41

Table 2. Threshold vibrational stresses in the exploitation of clamps

Tensile strength R_m (N/mm^2)	Dynamic bending strength (N/mm^2)	Dynamic compressive strength – fibers (N/mm^2)	Dynamic torsional resistance (N/mm^2)
1080	530	420	325

3.2 The Existing Process of Hardfacing on the Clamp

After heat treatment and mechanical processing with the removal of shavings, using the current technological procedure, the clamps are subjected to hardening of the working surface by the electric arc hardfacing process. The process of hardfacing the working surface of the clamp is carried out in workshop conditions. Fig. 5 shows a drawing of the clamp on which hardfacing is performed, while Fig. 6 shows the appearance of the working part of the clamp with hardfacing on the wear surface. This kind of maintenance procedure is technologically problematic, from the point of view of diagnostics of the state of wear and tear, through the process of exploitation. It often happens that the replacement of the entire clamps on the tamping aggregate is approached, due to complete wear of the welds and excessive wear of the basic clamped material, and this causes a stoppage considering that on one working machine, the function of tamping the stone under the thresholds is performed by 32 clamps. This maintenance approach is uneconomical and unreliable.

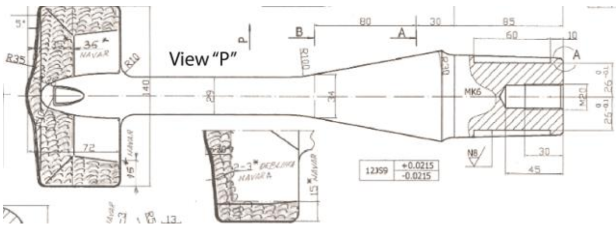

Fig. 5. Surface and position of the hardfacing on the clamp

Fig. 6. The appearance of the working part of the clamp with a hardfacing on the wear surface

The clamp tool elements are connected to the tamping hydraulic machine via a cone. The cone is processed with high quality and tolerance, with nominal sizes 1° 29' and 36'', which enables the creation of a highly stable and solid connection via a tension screw. Due to the exploitation and combined vibrating loads, this type of connection causes a solid connection, and it is often problematic to dismantle the clamps without heating to remove a worn layer and apply a new one on the worn surface. This maintenance procedure, i.e. demobilizing the tamping machine and sending it to the workshop is expensive and uneconomical. It often happens that inadequate maintenance of the working parts of clamps in the exploitation process causes excessive wear of the base material of the clamp, so such clamps do not perform their function well. In such cases, existing clamps are replaced with new ones, which further increase maintenance costs. Fig. 7a shows a case of excessive wear of the working surface of the clamp and the base material, where it is not possible to apply a hardfacing welding on the working surface of the clamp, while Fig. 7b shows clamps with the correct technical sizes. It should be noted that practice has shown that the process of regenerating the working surface of the clamp by welding the hard layer is feasible a maximum of 3 to 4 times due to the change of technical characteristics under the heat-affected zone. This problem can lead to frequent cracking of part of the clamp, which causes immobilization of the entire machine. The approach to the maintenance of clamps is by renewing the hardfacing using the electric arc hardfacing process, after abrasion, max. 3 to 4 times, and then replacing it with a new part is not the most sustainable solution in terms of savings, materials, time, finance, etc.

a) b)

Fig. 7. a) Excessive consumption of the working surface of the hardfacing and the base material of the clamp and b) A clamp with correct technical parameters

3.3 An Innovative Solution - The Application of Segmental Inserts on the Wear Surface of the Clamp

The abrasive working surface of the clamp of the tamping machine is an essential component of heavy machinery, especially the railway sleeper tamping machine. It is a key part that plays an important role in ensuring the functioning of these machines. The body of the clamp is a forging made of high-quality material that has increased strength to withstand the combined loads and stresses present in the exploitation process. Fig. 8 shows a clamp with an embedded segmental insert on the wear surface.

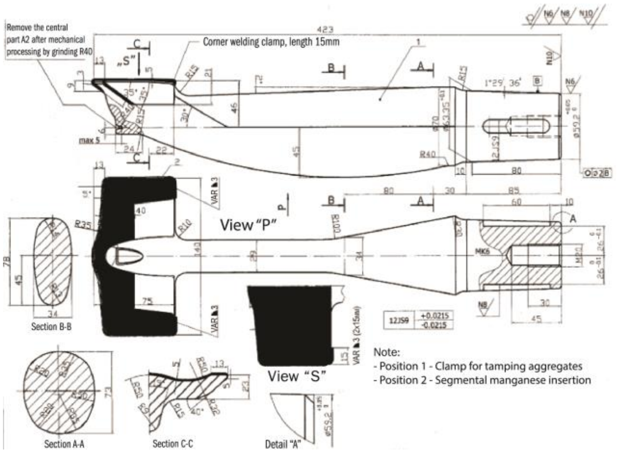

Fig. 8. Clamp with an embedded segmental insert on the wear surface

The analysis of the specific exploitation requirements of the clamp's segmental insert showed the optimal quality of the material with satisfactory resistance to abrasive wear and intense impact loads. These requirements can be achieved by multi-alloyed manganese austenitic steels, so-called Hadfield steels, quality G-X120Mn12 or X130Mn12, which, in addition to high manganese and carbon content, also contain chromium. Table 3 lists the chemical composition of the mentioned manganese steels. These steels are characterized by high strength value, high ductility and excellent wear resistance.

Table 3. Chemical composition of G-X120Mn12 or X130Mn12 [21]

Material	**Chemical composition (%)**					
	C	Si	Mn	Cr	P	S
G-X120Mn12	1.20	0.50	13.00	1.00	0.040	0.10
X130Mn12	1.20	0.50	12.00	0.8	0.035	0.10

Replaceable segments are designed to fit into the working surface of the clamp and have perfect contact without clearance, which provides good impact resistance, uniform wear, abrasion resistance and the ability to withstand the extreme demands of the combined loads of heavy construction railway machinery. The construction solution and design allow it to be produced using a simple technological process, hot plastic deformation, matrix forging, and casting in a mould. Fig. 9 shows the construction layout of the replaceable segment of the wear surface of the clamp of the tamping railway construction machine obtained by casting.

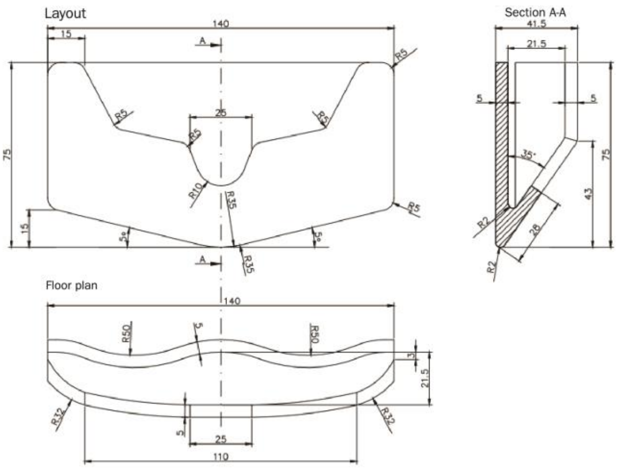

Fig. 9. Design layout of there-placeable segment of the clamp's wear surface

After heat treatment of the cast (forged or cold pressed) segment of the working surface of the clamp, the corresponding mechanical characteristics shown in Table 4 are achieved, which significantly affect resistance, wear and shelf life.

The hardness of this steel is about 200 HB (max. 250 HB) after heat treatment, but this value has little significance for evaluating machinability or wear resistance. The hardness of these austenitic manganese steels increases rapidly with deformation, so they must be evaluated differently. Also, an increase in tensile characteristics, wear resistance, impact resistance (toughness) depending on grain size and heat treatment was observed. Work hardening is the main characteristic of these steels because it affects their usability. One of the main characteristics of plastic deformation of metals is that the shear stress required for sliding increases continuously with the increase in shear deformation. The increase in stress required for sliding is called strain hardening or work hardening.

Table 4. Mechanical properties of manganese segments made of steel G-X120Mn12 and X130Mn12 after heat treatment and exploitation process

Tensile strength *Rm* (N/mm^2)	Initial hardness value (HB)	Hardness value after hardening by the exploitation process (HB)	Elongation *A* (%)	Toughness 20^{o}C (J)
≥800	200 ÷ 250	>320 (reaches up to 550)	≥40	≥90

In addition to innovative technical and technological features, the replaceable segments of the wear surface of the tamping clamp are also environmentally friendly. The segments are made of high-quality alloy steels that are emission-free, environmentally friendly and non-toxic materials.

3.3.1 Metallographic Characteristics of the Segmental Clamps Material

It is known that manganese steels are resistant to wear, especially if they contain chromium, as is the case with steel G-X120Mn12 or X130Mn12 and with 0.8% chromium, in the case that the segmental inserts are made by cold plastic deformation; they belong to the group of hard steels resistant to abrasion. Manganese austenitic steels have relatively low hardness, ranging from 200-250 HB [22]. They are resistant to abrasive wear only when their working surface layer is intensively plastically deformed in the cold under the influence of solid shock loads (squeezing) or under static load under pressure on the press. Alloying with manganese increases the hardenability of steel, and in unhardened steels, strength and toughness are improved. The addition of every 1% of manganese can lead to an increase in the tensile strength of structural steels by about 100 N/mm^2. Steels exhibit an austenite microstructure, regardless of the carbon content, if the manganese content exceeds 12%.

After manufacturing, the segmental insert of the clamp of the tamping railway construction machine, by casting or cold plastic deformation, is subjected to a heat treatment of hardening to a temperature >1100°C. This process produces an austenitic structure. The austenitic structure of that steel turns into martensitic during deformation (under pressure), therefore it is resistant to wear. The austenitic structure of that steel turns into martensitic during deformation (under pressure); therefore, it is resistant to wear. The martensitic transformation occurs when the stable austenite's cooling rate reaches the critical rate's value. Without prior release of carbon, austenite turns into a supersaturated α-mixed crystal, martensite. In Hadfield steels (G-X120Mn12 and X130Mn12), the microstructure of the steel before plastic deformation was purely austenitic, and after plastic deformation, martensite needles are observed in austenite grains [23].

These alloys are mainly known for their ability to be significantly hardened by the exploitation under load, i.e. there is an increase in hardness and strength on the surface, and the core remains tough. They are so tough and plastic that the segmental insert made of this steel (G-X120Mn12) has about 250 HB after installation, and when working under high loads, the hardness is as much as 550 HB, without material degradation. The reason is the transition of the austenitic structure to the martensitic during this hardening/strengthening. During impacts, dislocations of crystal lattices and different bonding of elements occur, so under impacts the material hardens and an austenitic structure becomes martensitic. This property makes them the first choice in many applications with repeated heavy loads (such as the case of the clamp of the tamping machine). This makes them unworkable or burdensome to the machine by turning either milling or drilling because they harden rapidly under the milling process.

Fig. 10 shows the increase in the hardness of the segmental inserts caused by the impacts with the stone during the exploitation time.

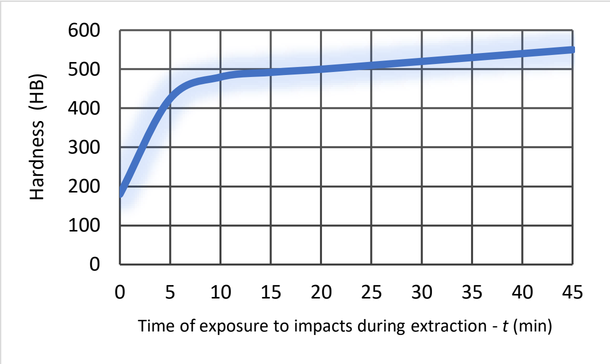

Fig. 10. Increase in surface hardness of segmental inserts over time

3.4 The process of Mounting and Dismounting Segments on a Clamp

The contact of the replaceable wear segment on the surface of the clamp of the submersible tool is an important technical detail. The replaceable manganese segmental clamp insert is very easy to assemble and disassemble. The installation-assembly process can be carried out in the field without demobilizing the tamping machine and sending it to workshops. Fastening is carried out by spot welding along the edge of the segment, using an electric arc process in two positions of 10 to 15 mm length on one side, as shown in Fig. 11. The joint weld is not accessible to abrasion by the exploitation process, so the weld remains intact and undamaged until replacement with a new segment. The clamp segments can be replaced on the field, i.e., in the exploitation process, by removing the joint weld with a manual grinder and installing a new segment. The whole process is carried out quickly and efficiently without disassembling the clamps from the machine, which is not the case with the traditional way of maintaining the clamps by welding the worn surface.

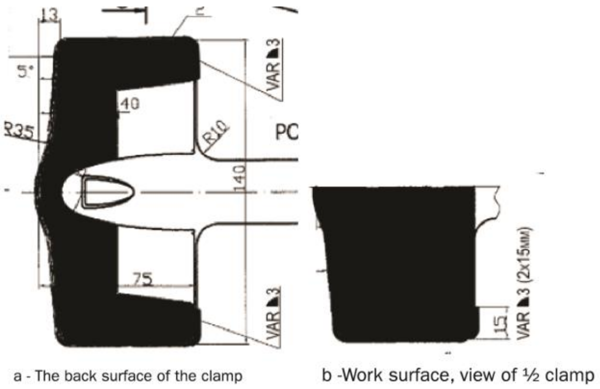

Fig. 11. The position of the segmental insert on the clamp and the method of fastening

4. RESULTS AND DISCUSSION

4.1. The results of the Wear of Tamping Machine Clamps

The unique shape of the replaceable manganese segment of the working surface of the tamping railway machine clamp makes it ideal for maintenance. It is designed to last longer, be easily and quickly replaced, and withstand the extreme demands of heavy machinery compared to traditional maintenance. This significantly saves time, makes the maintenance process efficient, and provides considerable economic justification for the savings in maintenance costs.

The research in real/natural conditions, before installation and after 100 hours of exploitation, revealed extremely uneven and increased wear of clamps with hardfacing onto the working surface and visible damage to the working surface of the base material clamp caused by wear on individual clamps, which affects the stability of the clamp as a tool. Very little significance has changed in clamps with manganese-replaceable segments. An overview of the change in mass as a result of the wear of the working surface of the clamp and the base material is given in Table 5 for the process of hardfacing of the clamp or in Table 6 for the process with embedded manganese segments on the wear surface of the clamp.

The mass of the clamps before exploitation, on which the scale was applied, was from 12.558 to 13.182 kg (Table 5), while it was from 13.05 to 13.10 kg on the clamps with embedded manganese segments (Table 6). This difference in mass when hardfacing the wear surface appears due to uneven hardfacing. In clamps with exchangeable manganese segments, the segment's mass is more accurate, considering that the segment has a mass of 680 g with a minimal deviation. The hardfacing on one clamp is determined by construction and should range from 500 to 600 g. The mass of the clamp without hardfacing and manganese segment is 12.20 kg.

Table 5. Loss of mass at the working wearing part of clamps with weld from worn surfaces

Mass of tested samples (12.20 kg)	**Clamps with weld from worn surfaces (500-600 gr)**							
	1	2	3	4	5	6	7	8
At the beginning of the tests (kg)	12.56	12.80	12.75	13.22	13.18	12.90	12.61	13.01
At the end of tests (kg)	12.02	12.18	12.13	12.35	12.31	12,30	12.04	12.35
Mass loss (g)	539	621	625	870	872	600	563	657
Mass loss (%)	4.3	4.9	4.9	6.6	6.6	4.7	4.5	5.1
Wear of the base material of the clamp (g)	181	19	75	0	0	0	158	0

Tabela 6. Loss of mass on the working-wearing surface of clamps with embedded manganese segments on the worn surface

Mass of tested samples (12.20 kg)	**Clamps with embedded manganese segments on the worn surface (680 gr)**							
	9	10	11	12	13	14	15	16
At the beginning of the tests (kg)	13.08	13.10	13.10	13.05	13.08	13.05	13.07	13.10
At the end of tests (kg)	13.02	13.05	13.05	13.00	13.00	13.00	13.00	13.02
Mass loss (g)	60	50	50	50	80	50	70	80
Mass loss (%)	0.45	0.38	0.38	0.38	0.61	0.38	0.54	0.61
Wear of the base material of the clamp (g)	0	0	0	0	0	0	0	0

Based on the research results obtained, it can be concluded that the manganese segments made of G-X120Mn12 showed good resistance to wear. This means that they are suitable and economically justified for this type of wear and, thus, the application.

4.2 The Material Costs of Maintaining the Tamping Machine Clamps

Investigations of material costs in the maintenance of the tamping railway construction machine with installed 32 clamps were observed for 12 months or for effectively spent 400 working hours. The following material costs were observed (Table 7): work on disassembling and assembling the tamping machine clamps, consumption of welding electrodes, welder costs for welding, value of the innovative insert, electrode for joining the insert, welder costs for joining segmental inserts and immobilization costs.

The costs of maintenance of one tamping aggregate with 16 clamps indicate that the maintenance cost of clamps with a coated wear surface was €13728.40, while the cost of clamps with an installed segment on the wear surface was 337.92 € (Table 7). This means that maintenance of this railway machine is 40.62 times less when using clamps with built-in segments. Also, the analysis of material costs revealed that the costs of reparative hardfacing of 32 clamps reach up to 42% of the price of a new set.

The shelf life of new impact clamps with coat on an abrasive surface in practice was up to 100 working hours until the next regeneration by hardfacing, while the shelf life of clamps with replaceable segments made of alloy steel G-X120Mn12 and X130Mn12 reached an average of 450 working hours.

Based on the results of the research, in addition to the above, other advantages of using segmental inserts made of G-X120Mn12 and X130Mn12 can be mentioned:

- High resistance to abrasion and impact toughness.
- Under stronger impacts and abrasion, the surface becomes harder and more resistant to wear.
- The manganese steel of the clamp segmental insert remains ductile underneath - as the surface wears - the outer layer becomes harder,
- With continuous influence of manganese, it can harden up to 550 HB.
- Can be cut with plasma, laser, water jet and acetylene.

Table 7. Material costs of maintaining the wear surface of the clamp under real conditions of exploitation after 400 hours of work

Costs for one tamping aggregate - 16 clamps	Unit of measure	Clamps with cladded wear surface		Clamps with a built-in segment on the wear surface	
		Amount	Costs (€)	Amount	Costs (€)
Work on disassembling and assembling the clamps of the tamping unit	h	128	896.00	-	0
Welding electrode E DUR 600 (450 g/clamp)	kg	57.60	570.00	-	0
Welder costs for welding worn surface	h	106.24	1,062.40	-	0
The value of the segment insert on the working surface of the clamps (0.7 kg x 12= 8.40 €)	euro	-	0	32	256.00
Electrode for connecting the segment insert	kg	-	0	1.6	8.00
The costs of the welder for the connecting of segmental inserts	h	-	0	7.4 (for 32 clamps)	73.92
*Clamp damage due to excessive wear	%	20	0	-	0
Costs of immobilization of the tamping machine for 12 months	h	160	11,200.00	-	0
*Shelf life of clamp	months	24		constant	
TOTAL (excluding costs marked with *) =			13,728.40		337.92

5. CONCLUSION

The application of reparative welding to the abrasive surface of the clamp tool by the electric arc welding process is a traditional technological maintenance procedure, which is separate from the technological development of this time. It can be qualified as an outdated, unreliable and ineffective process of clamp maintenance. Also, the results showed that the maintenance procedure has shortcomings, which are mainly reflected in the short operational life and lack of cost-effectiveness.

Using innovative replaceable segments made of manganese steel, installed on the abrasive surface of the clamps, the shelf life of the clamps is extended by 4.5 times compared to the clamps with reparative welding. In addition to the above, great material savings are achieved, productivity is increased, and downtime of the tamping machine is reduced, as well as the range and quantity of necessary spare parts. The material maintenance of the tamping machine is 40.62 times lower when using clamps with a built-in segment compared to the traditional way of reparative hardfacing.

Conflicts of Interest

The authors declare no conflict of interest.

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