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STUDIES ON THE THIN LAYERS DEPOSITED ON TOOLS STEEL

The paper describes an experimental study of thin layers obtained using the vibrating electrode method. Vibrating electrodes are used because they are effective for producing layers with high hardness and wear resistance. Before the depositions, the base material was polished with abrasive paper to remove any oxides and impurities. Furthermore, four electrodes made of Ti, TiC, WC, and stellite were used to deposit different layers on the surface of steel blades using an Elitron 22 installation. The tungsten electrode was used to improve mechanical properties, whereas the titanium electrode increased corrosion resistance. Both the substrate and the deposited layers have had their chemical composition, microstructure, and hardness analyzed. The substrate is made of medium-alloyed steel, which is commonly used to make plastic shredder blades. Following deposition, the samples were subjected to final heat treatments, including quenching and tempering. Furthermore, microhardness and microstructural analyses were conducted to assess the properties and surface morphology of the coatings.

Keywords: Shredder blade; vibrating electrode; hardness; treatments; thin layer deposition

1. Introduction

The current plastic materials industry faces a significant challenge in developing technologies based on the circular economy concept [1]. These challenges arise from the major limitations associated with plastic material reuse and recycling. According to the literature [1,2], this industry encompasses multiple types of plastic materials, such as polyamide, polyethylene, polypropylene, plexiglass, PVC, textolite, and ABS, which are derived from petroleum products. Given their vast range of properties and versatility, these materials serve as key components in many applications. The strong industrial interest in these materials is primarily due to their good corrosion resistance, electro-insulating properties, low specific gravity, favorable mechanical properties, low production cost, aesthetically pleasing appearance, and ease of processing [2]. However, they also have certain disadvantages, such as low temperature resistance and the dependence of mechanical properties on working temperature – i.e., most mechanical properties degrade at high temperatures. Additionally, they exhibit a high coefficient of expansion and a low heat transmission coefficient. Most importantly, limitations related to sustainable development – such as difficulties in recycling or non-recyclability – significantly restrict their use in some industries [2].

Due to the growing interest in plastic recycling, various studies have aimed to develop technologies and materials for recovering plastic waste. V. Lahtela et al. [1] proposed an innovative method for reprocessing multilayer plastic waste from food packaging to produce new products through injection molding. According to their study, recycling this type of product is particularly challenging due to the wide range of properties exhibited by the collected waste, including a melt flow rate between 2.96 g/10 min and 48.4 g/10 min, and elongation between 2% and 289%.

Zhongwei Wu et al. [3] established a mechano-chemical model and analyzed the degradation and regeneration mechanisms of thermosetting phenolic plastic waste. Their study highlighted the influence of process parameters – such as speed, time, and temperature – on recycling efficiency. Arul Arulrajah et al. [4] investigated three types of recycled plastic granules and

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two types of demolition waste to assess their potential as road construction materials, evaluating their stiffness and resilience.

Yat Choy Wong et al. [5] demonstrated in their study that incorporating 10% recycled plastic waste and 10% recycled crushed glass into concrete mix designs has the potential to create sustainable concrete footpaths. This approach would significantly reduce the amount of plastic and glass waste that ends up in landfills.

Tibor Kvakaj et al. [6] conducted a literature review on strain insertion in materials with medium and high stacking fault energy under ambient and cryogenic temperature conditions. Wong et al. [7] analyzed the wear mechanism and performance of PET material chopping knives, considering their geometry and orientation. They observed that blade wear occurs progressively due to abrasion, adhesion, and oxidation. Their study also demonstrated that blades sharpened on both sides with a spiral orientation achieved a recycling efficiency of over 97%, a retention rate of 2.6%, and a chopping efficiency of approximately 70%.

Wong et al. [8] examined various types of plastic shredders, including single-axis and dual-axis designs. While the overall structure and design of these shredders are similar, shredder blade geometry plays a crucial role in determining efficiency. One of the most efficient designs was the plastic shredder reported by Biddinika in 2017 [9], which featured a single shaft with three mobile longitudinal blades and two static blades attached to the structure. However, the main issue remained the rapid wear of the blades.

Recent studies, including the work by Hsu et al. [10], emphasize that multi-element nitride coatings, such as TiAlN and AlCrN, significantly improve the wear behavior and service life of tool steels like AISI H13 (Hsu et al., 2024). These multilayer films can be optimized through varying deposition conditions, notably the N2/Ar gas ratios, which influence the mechanical properties and adhesion on tool surfaces. Moreover, Yaqoob et al. reported similar findings, highlighting improvements in cutting performance when using PVD and CVD-coated tools, indicating that combinations such as Ti(CNO) can enhance machinability under high-stress conditions typically encountered when machining high-strength steel [11].

This study addresses the damage of shredder blades following the impact with particles with high hardness (impurities from the material to be chopped such as: metal scraps, ceramic scraps, etc.) and progressive wear. Therefore, the paper proposes a method of refurbishing these damages, respectively wear, which can be applied easily and without high economic costs. Thus, the work analyzes the deposition of superficial layers with different types of electrodes, through the method of discharging electrical impulses.

2. Materials and methods

As with most existing materials, plastic materials have a limited working period; once they become end-of-life products, some techniques must be developed to recover and recycle the resulting waste. Therefore, if that type of plastic can be recycled by melting, the plastic products are ground, and the processed material is reintroduced into the technological route for obtaining other plastic products. Also, the plastic waste can be recycled by incorporating different amounts into the composition of different types of binders or concrete [4]; however, to make it suitable for this kind of recycling, the initial plastic products must be shredder into particles with millimetric diameters.

2.1. Materials

In this study, the blades used in shredder machines as that presented in Figs. 1 and 2 are approached.

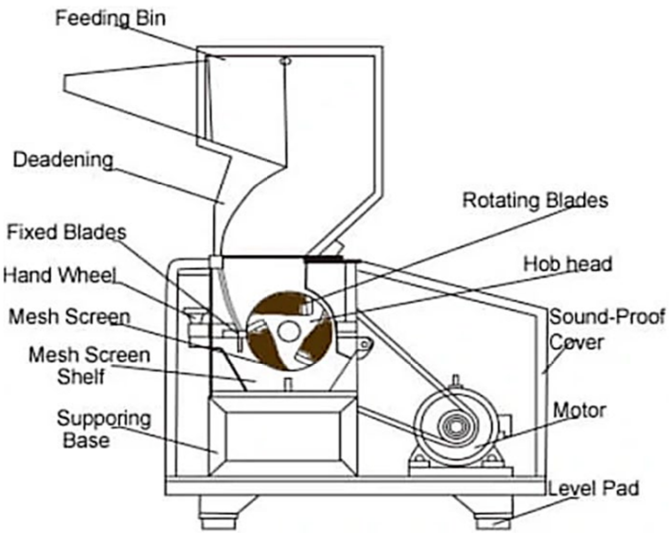

Fig. 1. Shredder machine scheme [12]

Fig. 2. Shredder machine [12]

As can be seen the shredded plastic have dimensions in the range of 6-10 mm (Fig. 3), depending on the size of the holes in the outlet sieve. The ground plastics are collected in bags and go to the injection molding machine to obtain new products.

Shredded waste from plastic largely retains mechanical strength and chemical stability, but shredding can reduce structural integrity, and their efficient recycling allows for transformation into new products, contributing to the circular economy and reducing environmental impact. Shredded waste (800-980 kg/m^3) retains tensile strength (~20-50 MPa) and impact strength, but loses structural integrity, being recyclable into products such as pipes and containers, provided proper sorting and cleaning.

Fig. 3. Plastic ground

The machine has two fixed blades and three mobile steel blades inside, which wear out at specific intervals. The wear period of the three blades depends mainly on the amount of plastic processed and the type of plastic ground.

In order to avoid periodically replacing the blades with original ones, an attempt was made to rebuild the active edge, which could reduce the processing costs associated to the blades replacement. Therefore, in this study, an innovative method or restoration of the shredder blades is proposed. Accordingly, the electrical pulse discharge method was successfully used for local reconditioning of parts. After surface treatment, the blades have high hardness and wear resistance.

The base material on which the deposits were made comes from a blade that presents missing zones. Moreover, to assure the experiments repeatability four different types of layers have been deposed: high-purity titanium (Ti), titanium carbide (TiC), tungsten carbide (WC) and stellite (W-Cr-Co alloy).

The shredder blade used (Fig. 4) for the experiments has an increased hardness (over 63 HRC), which proves that it was subjected to quenching and tempering treatments. The experiments aimed at eliminating chipping defects of the active edge by depositing thin layers and local rectification.

2.2. Methods

2.2.1. Deposition method

The refurbishing of the damaged blades was performed by the vibrating electrode method, thus avoiding additional thermal processing: annealing, deposition of layers, quenching, rectification etc. In this study, an ELITRON 22A type installation was used for the vibrating electrode deposition. The operating parameters for each type of electrode are presented in TABLE 1.

TABLE 1

Working parameters for each type of electrode

Electrode	Vibration amplitude
Titanium	0.08 mm
Stellite	0.14 mm
Titanium carbide	0.14 mm
Tungsten carbide	0.12 mm

These parameters are important because the characteristics of the deposited layer depend on the electrode material, the pulse discharge parameters and the composition of the medium between the electrode and the substrate.

2.2.2. Microstructural analysis method

To analyze morphology of the thin layers deposited with the 4 electrodes, a Vega Tescan SEM microscope and different magnification powers were used.

The chemical composition of the base material was determined by quantitative spectral analysis on the Foundry Master optical spectrometer. The weight amount of each element from the composition is presented in TABLE 2.

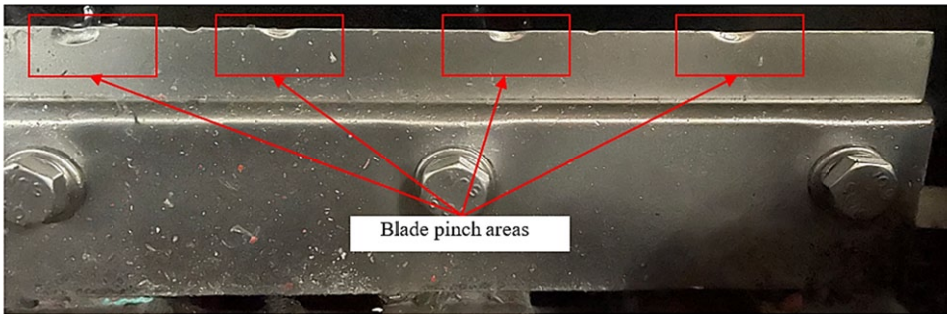

Fig. 4. Shredder blade

TABLE 2

The chemical composition of the base materials (shredder blade)

Element	Cr	C	Mo	Si	Mn	Ni	oth.	Fe
%, wt.	11.40	1.71	0.80	0.31	0.23	0.23	1.02	balance

2.2.3. Hardness analysis method

The hardness measurements for the base material were performed on a Wilson Wolpert universal hardness tester, type 751N. The evaluations were performed through the Rockwell method, with a conical diamond indenter and a pressing weight of 150 Kgf (approx. 1500N). After depositing the thin layers with the four electrodes, the microhardness measurements were conducted by Vickers method, with a pressing weight of 50 g.

3. Experimental Section

3.1. Microhardness evaluation

Considering the low thickness (a few tens of microns) of the deposited layer, the hardness of the deposited layer was evaluated through microhardness tests so that the obtained values would not be influenced by the hardness of the base material.

TABLE 3 presents the microhardness values of all four types of deposited layers. As can be seen, the deposition with the WC electrode produced a layer with a very close hardness to that of the base material.

TABLE 3

The hardness values of the base material and the deposited layers

Teste surface		Hardness
Base material	Quenched and tempered	67.51 HRC
Deposited layer	Ti electrode	725.96 HV 50
	TiC electrode	772.30 HV 50
	WC electrode	975.66 HV 50
	Stellite electrode	862.58 HV 50

The lowest hardness was observed for the layer deposition with the Ti electrode, while the TiC layer had a microhardness value that was only 6% higher. The microhardness of the layer deposited with the stellite electrode was almost 19% higher than that of the Ti layer; however, it was 12% lower than that obtained with the WC electrode.

The hardness evaluation reveals that the vibrating electrode deposition method can be successfully used for local reconditioning of the cutting edge of the plastic shredder blades. It is a solution that can be used if the blade has no other defects or when the edge wear is not excessive.

3.2. Microstructural analysis

The thin layers obtained by electrodeposition of high-purity titanium (Ti) have a compact appearance, with few and very fine cracks, without voids of filler material (Fig. 5).

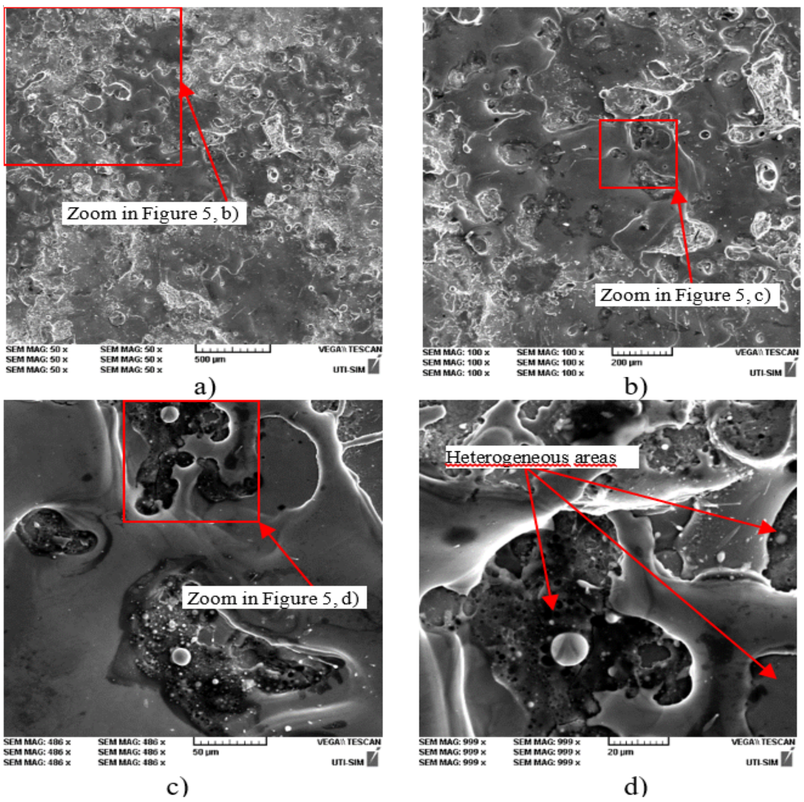

Fig. 5. The microstructure of the Ti layer deposited on steel surface, at different magnifications: 50×, 100×, 486×, 999×

Titanium carbide (TiC) electrode deposits have a porous appearance, with local cracks (Fig. 6). The combination of elements in the molten metal bath increase the values of wear resistance and hardness, but for good compactness of the layer, an additional layer is required either with the same electrode or with a different electrode as also demonstrated in [13-15].

Tungsten Carbide (WC) layer has an increased hardness and wear resistance [13,14,16-20]. Tungsten carbide adheres

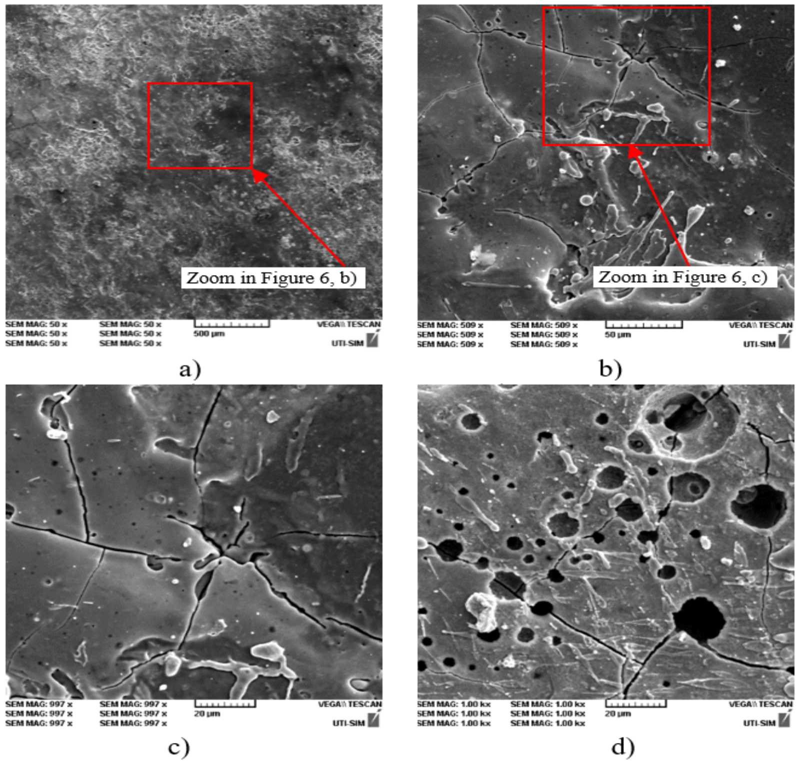

Fig. 6. The microstructure of the TiC layer deposited on steel surface, at different magnifications: a) 50×; b) 500×; c) 997×; d) 1000×

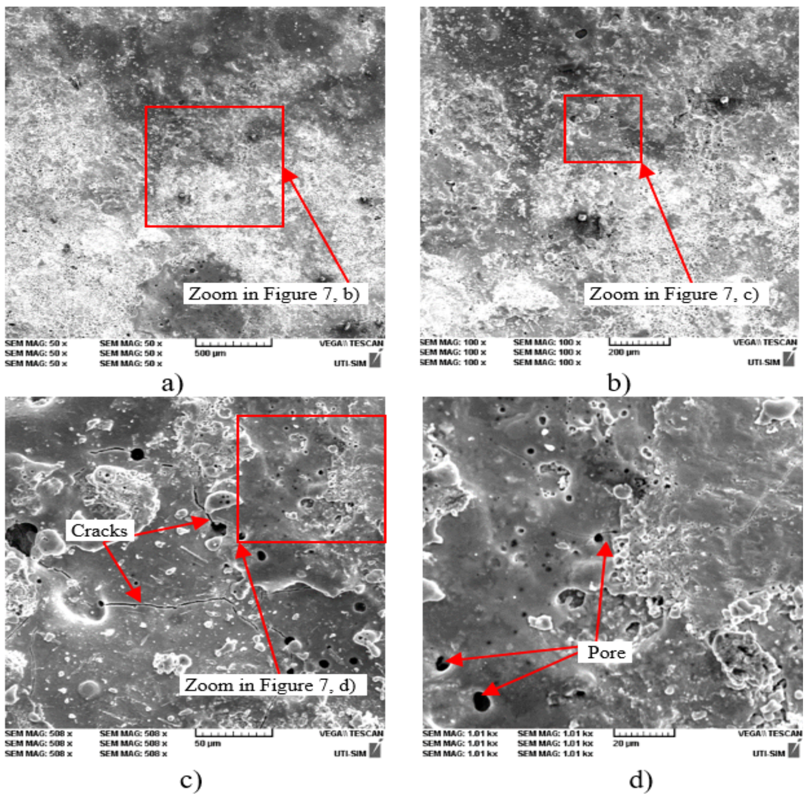

Fig. 7. The microstructure of the WC layer deposited on steel surface, at different magnifications: a) 50×; b) 100×; c) 500×; d) 1000×

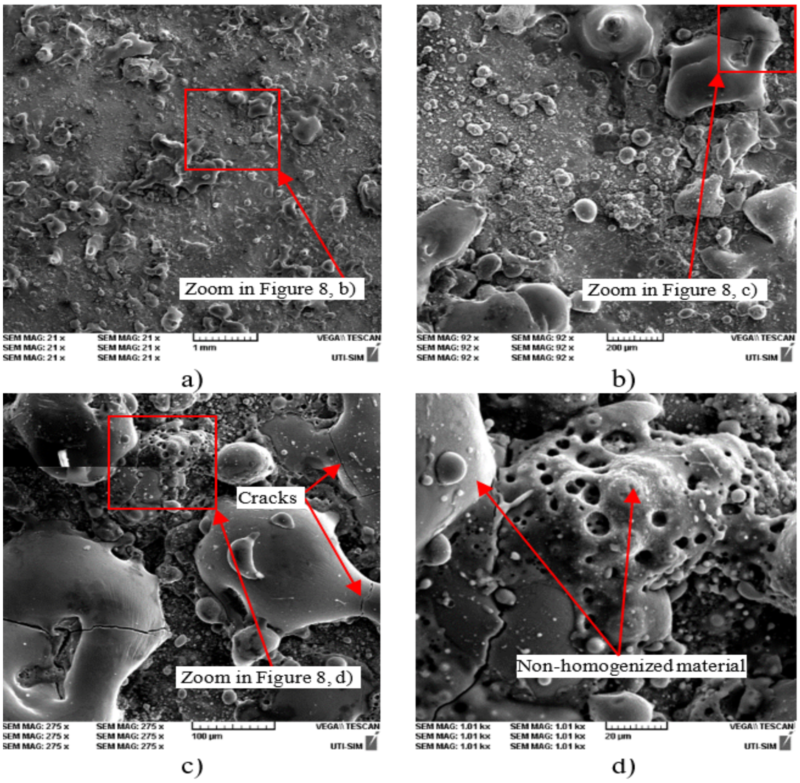

Fig. 8. The microstructure of the stellite layer deposited on steel surface, at different magnifications: a) 50×; b) 100×; c) 275×; d) 1000×

well to the surface of the base materials, because it locally melts the surface of the shredder blade and creates a highly resistant mixture of metal carbides.

Stellite is a complex alloy of several W-Cr-Co chemical elements that at high temperatures will combine with the chemical elements in the base material, generating an advantageous change in the properties of the coated product. The microstructure of the deposited layer by a single pass shows a compact layer.

Microstructural analysis reveals the characteristics of each type of layer. Some electrodes (Ti, WC, and Stellite) produced homogeneous structures after a single deposition, whereas others (TiC) required a subsequent deposition to ensure crack coverage and homogeneous morphology.

4. Conclusions

The quality of the surface obtained through deposition using the vibrating electrode method depends on both the chemical composition and quality of the electrode, as well as the layering sequence. In this study, Ti, TiC, WC, and stellite electrodes were used. Microstructural analysis revealed that surfaces deposited with Ti and WC electrodes were significantly smoother, more compact, and exhibited fewer microcracks compared to those created using TiC and stellite electrodes. While titanium carbide and stellite formed strong bonds with the base material, creating homogeneous layers, they also developed pronounced cracks due to differences in the coefficients of expansion and contraction between the base material and the deposited layer.

The vibrating electrode deposition method does not alter the operational conditions of shredder blades, allowing refurbished products to function under the same conditions as the original ones.

Based on the obtained results, low-carbon steel can be effectively used for manufacturing shredder blades, while various electrode types can be employed for refurbishing and repairing damaged areas.

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