

Article

Silver Alloy Surface Modification for Mechanical Property Enhancement in Aviation and Transportation

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Abstract: Silver alloys are often used for electrical switches in railway transportation. However, a well-known issue with these switches is their relatively short application period due to certain disadvantages of silver alloys, mainly their low hardness and low resistance to abrasive wear, in contrast to their excellent electrical conductivity. Therefore, the main goal of this study was to increase or maintain the hardness of the surface layer in order to extend the life of worn parts without compromising their electrical properties. Instead of ceramic particles, as in other studies, metallic powders were used, which could increase the electrical and/or thermal properties of silver alloys. The following work presents the use of laser processing as a relatively new technique for metal and metal alloy surface processing technology. In particular, a process based on the melting of silver (Ag) with metallic powders, such as chromium (Cr) and nickel (Ni) particles, is presented. The aim was for these powders to create intermetallic phases with a silver matrix in the obtained surface layer, significantly improving the mechanical properties based on the formation of the phases coherent or semi-coherent with the silver matrix. Regarding the original practical implications of this work, it was important to investigate the possibility of applying fibre laser for surface property enhancement. The scientific aim was to describe the changes in microstructure and compounds that occurred in the laser-remelted surface silver layer after Ni and Cr particles were fed into the basic silver material. It was concluded that the surface layer obtained after chromium application was without cracks and defects and had a higher hardness than the untreated material. A three-zone structure was also found in the obtained surface layer: (1) the remelted zone, (2) the heat-affected zone, and (3) the matrix material. The remelting zone revealed a higher hardness compared to the untreated material, reaching 92 HV0.3, which is more than twice the initial hardness value.

Keywords: surface treatment; fibre laser; silver alloys; laser feeding; metal powder



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1. Introduction

This paper discusses laser processing as part of the new generation of techniques used in metal surface technology. The mechanical and physical properties of silver alloys have caused their use to continually grow, especially for electrical uses, e.g., in railway electrical networks and traction for switches. The most important properties determining their use include their good machinability, good electromagnetic shielding properties, high electrical conductivity (6.3×10^7 Siemens/m), and thermal conductivity in the range of 429 W/mK, which is relatively high, even compared to aluminium with its thermal conductivity of 185 W/mK. These alloys are also easily recycled. Electrical and thermal conductivity are closely related. Pure silver has the highest electrical and thermal conductivity of all metals and the lowest contact resistance. Electrical conductivity determines how well a material transmits an electrical current. Copper wires are often thought to have excellent electrical conductivity. For the most part, good conductors of electricity are also good conductors of heat. Silver has the highest electrical conductivity of all metals. In fact, silver defines conductivity, and all other metals are compared to it. On a scale of 0 to 100, silver is 100,

copper is 97 and gold is 76. Due to this property and the fact that it does not spark easily, silver is commonly used in electrical circuits and contacts. It is also used in batteries, where reliability is required and weight limits apply, such as those in portable surgical instruments, hearing aids, pacemakers, and equipment for space travel. Nevertheless, they present strong disadvantages in their relatively low wear resistance and hardness, which can be a problem for long-term usage, such as in switch elements. The combination of laser surface treatment and addition of different types of metallic powders in the surface layer has been identified as a possible solution for this [1–3].

Surface treatments such as laser alloying or the remelting of metals and their alloys are typical examples of applications in which the diode laser shows advantages compared to other lasers, e.g., CO₂. Surface treatment requires a specific amount of heat transfer to ensure an evenly hardened surface with the expected properties. In the presented work, surface treatment was performed using an ytterbium laser. According to Shukla and Lawrence, a diode laser was chosen due to properties such as its shorter wavelength of electromagnetic radiation compared to conventional lasers previously used for the surface treatment of engineering materials, which increases the energy linearity and thus the precision of surface processing [4].

The past decade has seen a significant growth in interest in using laser techniques to both improve surface properties and perform cutting or welding. Laser surface treatment techniques, such as remelting and surface alloying, are increasingly used to improve the mechanical properties and tribological properties of all groups of metal alloys. These applications of lasers for surface treatment allow for a wide range of thicknesses of the treated surface to be obtained, and the average depth of remelting is usually between 5 µm and 5 mm [5–8].

Figure 1 presents the technological development of diverse laser applications with several types of metals, where laser remelting and alloying are still in the developing phase [9,10].

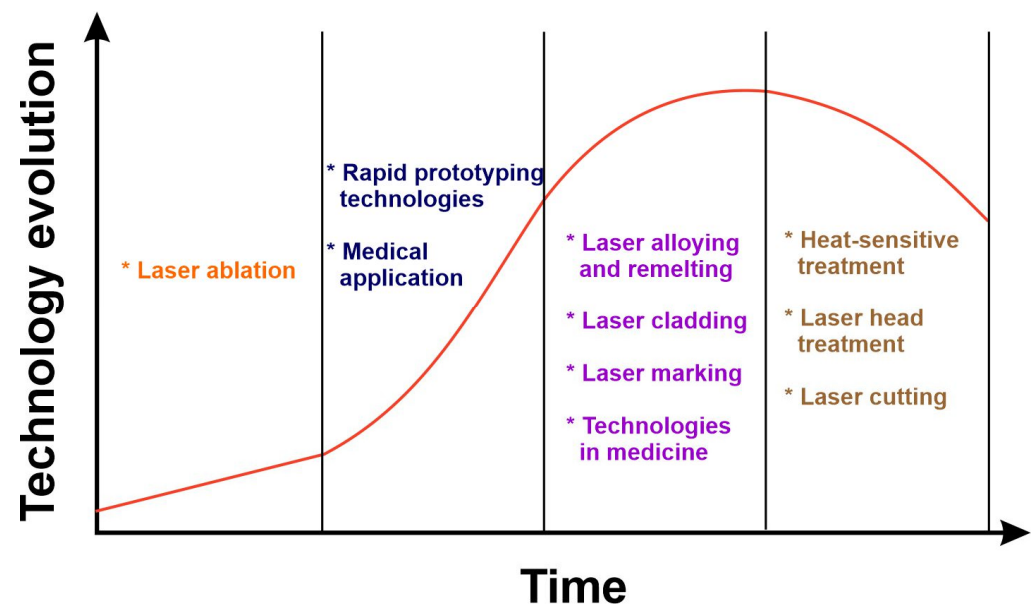


Figure 1. Technology life cycle in the field of laser technology used in materials science.

Materials such as metals and alloys are soft and ductile, which enables them to resist cracks under higher stress levels and loading, while hard and brittle materials possess low fracture toughness and are prone to crack propagation at lower stresses and loadings; therefore, it would be reasonable to introduce additional alloying elements to the silver surface layer, which could build a quasi-composite fraction and thus improve the wear resistance and hardness of silver-made electrical switches [11,12].

It is also possible that some of the introduced powder dissolves in the silver matrix via diffusion and thus increases the stresses occurring in the microstructure, creating a solid solution combined with the undissolved part of the metal powders used. This causes an increase in the stresses occurring in the material, e.g., due to the strengthening with second-phase particles, which is most often described by two mechanisms: the Orowan–Ashby and Mott–Nabarro or Friedel mechanisms [13,14].

Therefore, from the scientific perspective, one of the most important research aims was the investigation of the microstructure and enhancement of the mechanical properties; additionally, improvements in the hardness of the surface are very important for practical use. The microstructure and its compounds were investigated using the Ag–Cr and Ag–Ni equilibrium diagrams. The structure is a double system in which eutectics occur with limited mutual solubility of both metals. The determination of the laser treatment parameters is also important, particularly the laser power, to achieve a high value of layer hardness to protect the new developing material from losing its properties and to make the tool surface more resistant. Furthermore, EDS microanalysis was applied to determine the chemical composition of the created surface layer [15–20].

The silver alloys used in different transportation branches, e.g., for switches, show some disadvantages mainly concerning their low hardness and, relatedly, wear resistance. Therefore, the first aim in our study was enhancing the hardness of the surface layer to extend its lifespan without compromising its electrical properties. For this, metallic powders were used instead of ceramic particles (WC, NbC, VC), which could increase the electrical or thermal properties of silver. DSC analysis was applied to determine the thermal stability of this alloy, as well as the melting point shift and value compared to the pure Ag basis used [21,22].

Silver alloys are generally characterized by low strength, relatively low density, intermediate thermal stability, and creep resistance, with promising mechanical properties at elevated temperatures when combined with other phases fed into the surface layer. The introduction of nickel and chromium via laser treatment into the Ag matrix can increase the mechanical, tribological, and corrosion properties of the composite layers through the presence of undissolved Cr particles, as well as the formation of intermetallic Ni phases. For alloying, both powders were used in a 1:2 mixture because of the lower solubility of nickel in silver (approx. 3%) compared to chromium (approx. 6%). The assumption was that these powders with the silver matrix create diverse types of intermetallic phases, significantly enhancing mechanical properties such as coherent or semi-coherent phases. Preliminary research and a review of the literature have shown that the introduction of Cr and Ni into the molten pool during surface alloying forms a hard and wear-resistant layer on the surface of the aluminium alloy [23–29].

In this study, the effect of the added alloying elements on the microstructure and hardening was analysed. The mechanical properties of the zones of the surface layer were evaluated by employing microhardness and adhesion tests, as well as by characterizing its depths and surface quality. To avoid the formation of coarse particle conglomerates on the surface, the mechanical properties were improved and the optimal treatment parameters were proposed. Another aim of the conducted research was to investigate the microstructural changes and mechanical properties after laser remelting and/or alloying with the addition of Cr/Ni metal powder.

2. Materials and Methodology

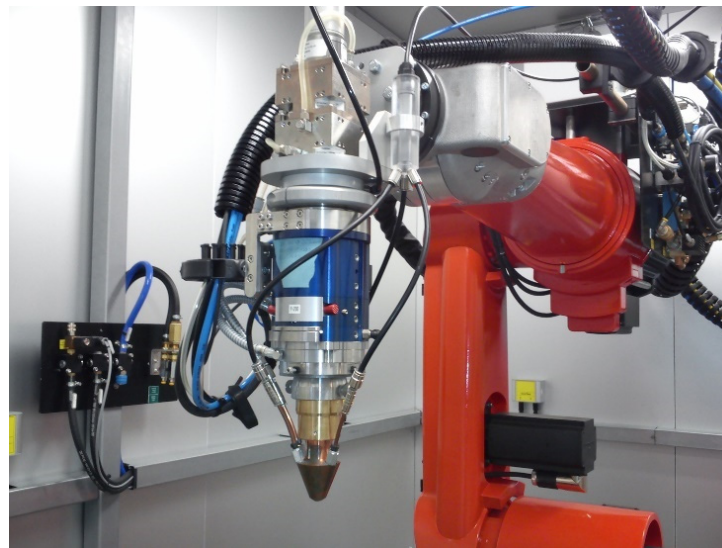
2.1. Materials for Investigation

As a material for investigation, 0.99 purity mint silver was used. Two metal powders were applied for alloying: chlorine (Cr) and nickel (Ni). The properties of the powders are listed in Table 1.

Table 1. Selected physical and mechanical properties of the materials.

Property	Cr	Ni
Density, kg/m ³	15.69	4.25
Vickers hardness, HV _{0,05}	3400	1550
Melting point, °C	2870	3140
Thermal expansion coefficient α , 10 ⁻⁶ /°C	23.5	8.3
Grain size, μm	80	5
Mixture ratio	2	1

To investigate the treated Ag surface layer, a specially chosen laser system was applied. Surface treatment was performed using the fibre Ytterbium laser system YLS-4000 (IPG Photonics, Oxford, MA, USA), equipped with a head to obtain a wavelength of $\lambda = 1070$ nm (Figure 2). The highest power value of the laser beam was 4 kW. The head was placed on the special six-axis REIS RV30-26 (Reis Robotics, Obernburg, Germany) mounted on the dedicated tilt-and-swivel positioning system. The laser alloying itself was conducted in a protective argon gas shielding atmosphere. The gas was supplied with two independent nozzles. The first of the nozzles was tilted at a 30° angle to the sample plane, and the second was tilted at 90 degrees. The first nozzle was placed to provide the alloying of chromium or nickel powder in the molten metal area. The second nozzle was set to provide the protective gas for air oxidation protection.

**Figure 2.** YLS-4000 fibre ytterbium laser used for remelting and alloying.

The maximum power value of the laser beam was 4 kW. The laser head was placed on a special six-axis REIS RV30-26 mounted on a special tilt-and-rotate sample mounting system. The laser alloying process was performed in a protective argon atmosphere to protect against the effects of the external environment. Gas was supplied using two independently located feed nozzles. The first one was inclined at an angle of 30° to the sample plane, while the second one was inclined at an angle of 90°. The first nozzle was placed to ensure proper dosing of the alloying powder of chromium or nickel (Figure 3) in the molten metal area, and the second nozzle was designed to supply a shielding gas to protect against oxidation of the treated surface.

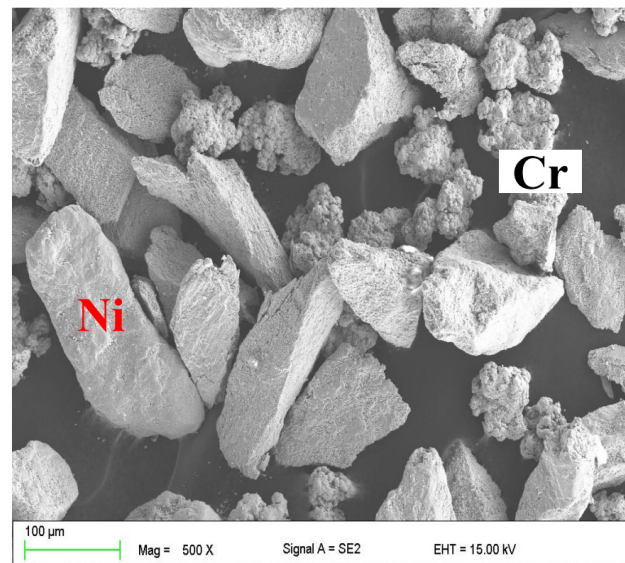


Figure 3. Cr/Ni powder used for the surface layer through feeding into the Ag alloy.

The grain sizes of the chromium and nickel powders used ranged from approximately 60 μm to 130 μm . These were determined to be appropriate because too small a granulation resulted in complete alloying in the matrix, while too large a powder particle size caused difficulties in mixing the powder with the matrix during alloying as a result of the relatively low wettability of large powder grains. Particular attention should be paid to removing moisture and/or dirt from the treated surface and powder prior to the process. The presence of moisture may cause significant increases in surface porosity and roughness, which adversely affect the obtained strength properties and quality of the microstructure of the surface layer. Before processing, the metal powders were dehydrated in a laboratory dryer, at a temperature of 110 $^{\circ}\text{C}$ for 12 h. Before surface treatment, the aluminium samples were mechanically ground on a Tegramin 30 Struers laboratory grinder using sandpaper with a gradation of 80 μm , 40 μm , and finally 15 μm . In the next stage, the polished surfaces were cleaned in an ultrasonic scrubber and washed with ethyl alcohol. The prepared surface was covered with a flux (lithium chloride with methyl alcohol).

To remove alcohol and moisture immediately before the process, the sample was dried on a heating plate at a temperature of 423 K. The flux used (paste) had a double effect. First, it allowed for a significant reduction of oxides on the surface, and second, it increased the absorption of laser radiation, thus increasing the depth of the melting. The powders were dried prior to use to avoid a possible oxidation base due to water coming into contact with the molten silver surface layer.

The Cr-Ni powder was introduced into the molten pool using a feeder at a constant rate of 4.5 g/min (Figure 3). For surface remelting, we used a square laser beam with a size of 3 $\times$ 3 mm and power of 3.0 kW. The linear laser scan rate of the beam was set at 0.5 m/min. Argon gas was used as a protective atmosphere, in order to protect the substrate from oxidation, directed through a nozzle on the remelted sample surface during remelting at a blow angle of 45 degrees and an amount of 8 L/min Argon 5.0.

In preliminary investigations of the fibre laser, the speed of the laser beam was set between 0.25 m/min and 0.75 m/min, so the value was 0.5 m/min for all samples. This was to determine the best relationship and combination between the laser power and the laser speed and their influence on the nature of the obtained metal surface. For values of more than 3 kW, the surface obtained was too rough even for the measuring range of the scale.

All the other work parameters are presented in Table 2. To ensure good work parameters, the investigations were carried out at a constant remelting process rate, varying the laser power from 2.0 kW to 3.0 kW.

Table 2. Parameters of the fibre laser.

Parameter	Value
Laser scanning rate, m/min	0.5
Peak power, W	2000–3000
Power feeding rate, g/min	4.5
Argon flow rate through the nozzle	8
Dimensions of the laser beam focus, mm	3 × 3

2.2. Investigation Methodology

Before treatment, the samples were cleaned and ground with abrasive paper with a granulation of 60–15 μm . After grinding, an ultrasonic scrubber was applied for final cleaning at 45 °C for 25 min to remove residues from the polishing and grinding process.

The microstructure of the surface layer and its cross-section were examined using a light microscope with a magnification between 50 $\times$ and 500 $\times$. For a higher magnification range, a scanning electron microscope was used with a backscattered electron detector or secondary electron mode. The voltage was set at 20 kV.

The EDS microanalysis technique was applied to measure the chemical composition of the created surface layer, and the microprobe was mounted on the Zeiss Supra scanning electron microscope (Zeiss, Oberkochen, Germany). The Vickers microhardness (HV) was measured on a plane designated as the x-plane by applying a load of 300 gf for 15 s using a Vickers hardness tester.

3. Results and Discussion

The macro- and microstructure investigations performed using the fibre laser allowed for comparing the surface layer as well as the shape and depth of the remelting area. The cross-sections of the layers achieved by the alloying process are shown in Figures 4 and 5. A general remark can be made that an increased laser power causes increases in the remelting depth and the surface roughness of the remelted area.

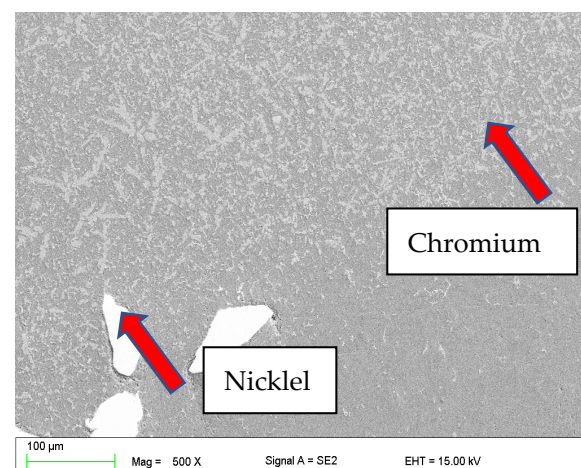


Figure 4. Surface layer after Cr/Ni powder was fed into the Ag alloy; power: 2.0 kW; laser speed: 0.5 m/min.

The achieved microstructure is presented in Figure 6. Concerning the distribution phases that occurred in the Ag-Cr-Ni alloy, the microstructure was very well solidified without any defects or failures; some discontinuities were found, but for higher laser powers, the thickness was as high as approximately 143–380 μm , depending on the power. The dendritic arms of the slowly solidified Ag matrix are relatively visible, revealing the heat transfer direction after the laser beam treatment at room temperature.

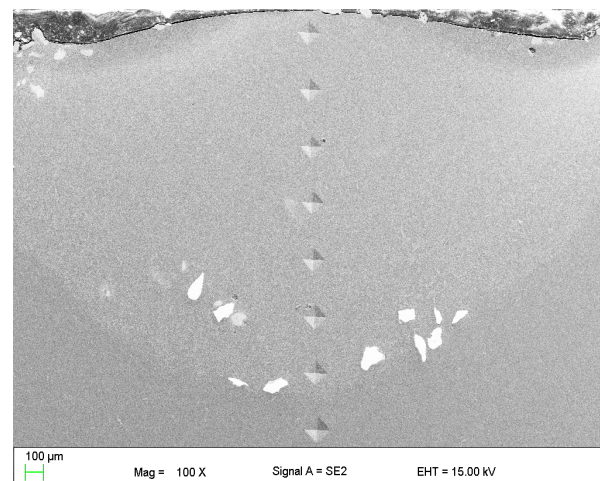


Figure 5. Microstructure of the surface layer after Cr/Ni powder was fed into the Ag material; power: 2.5 kW; laser speed: 0.5 m/min.

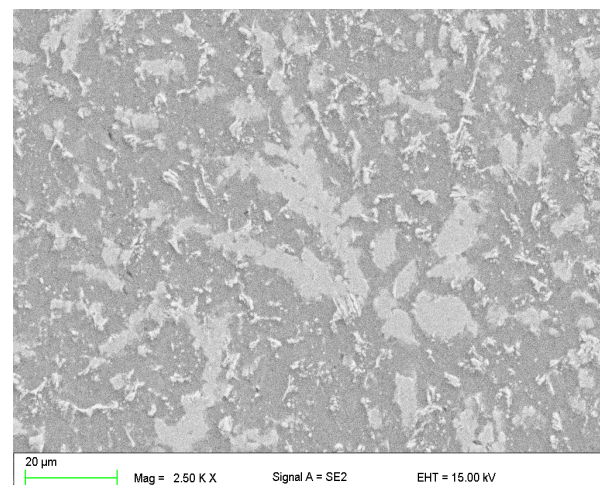


Figure 6. Microstructure of the surface layer after Cr/Ni powder was fed into the Ag material; power: 3.0 kW; laser speed: 0.5 m/min.

The three-zone-like nature of the surface cross-section was detected with the presence of the remelting zone, the heat influence zone, and the intermediate zone, and the substrate material.

The alloyed chromium and nickel metal powder particles occurred as loose particles with a size between 20 and 100 μm , evenly distributed in the Ag matrix (Figure 6), and did not create any coarser conglomerates (EDS, Figure 7).

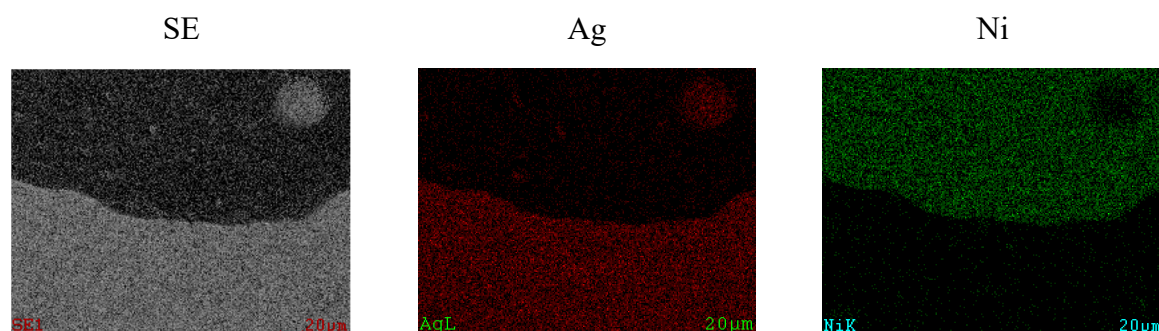


Figure 7. EDS of the surface layer after the Cr/Ni powder was fed into the Ag material.

The EDS point analysis, presented in Figure 8 and Table 3, reveals the chemical composition of the alloyed area around the Cr particles. So, in the case of this powder, the metallic material is not dissolved in the silver matrix but remains in the form of the primary Cr particles. There is no evidence for the dissolution of the Cr Ni particles in the matrix, otherwise the element concentration in the Ag matrix would have been possible to measure and the element would have been visible in Figure 7.

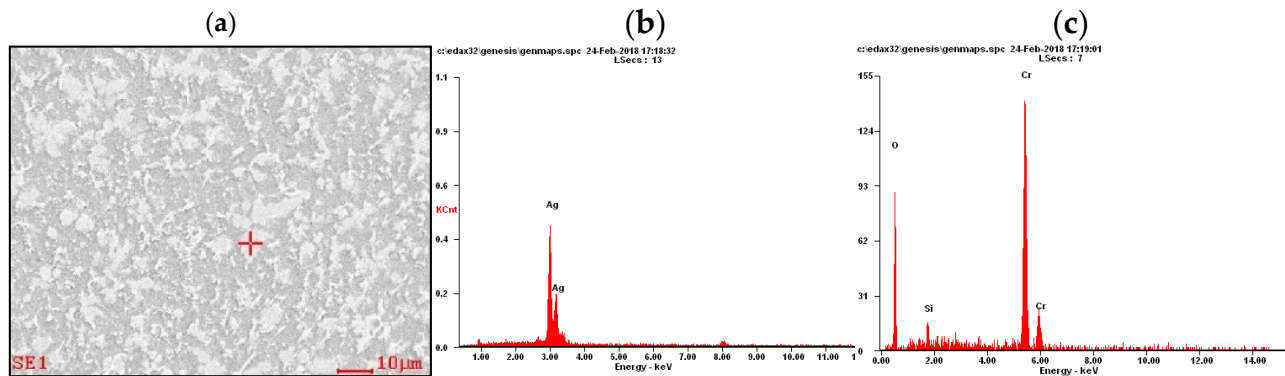


Figure 8. EDS pointwise analysis of the chemical composition performed: (a) Surface layer cross section of the Ag alloy, power 1.5 kW, (b) area of the SEM image, and (c) area of marked square in SEM image.

Table 3. Quantitative EDS analysis of the AgCrNi surface after laser treatment for the areas marked in Figures 5 and 6.

Chemical Element	Concentration, %	
	Mass, %	Atomic, %
Point 1		
Ag	100.0	100.0
Cr	0.0	0.0
Point 2		
Cr	76.91	51.83
Si	2.55	3.19
O	20.54	44.98

During heating, the Ag-Ni-Cr alloy sample showed one solution with a maximum transformation temperature of 381 °C (Figure 9); compared to pure silver, a lower melting point was found in accordance with the TTT diagram (time–temperature–transformation) of this quaternary alloy.

For the Ag-Ni-Cr alloy, the maximum temperature during heating was found to be 381 °C. This was lower than that for pure silver Ag 99. This was due to the presence of alloy additions in the form of chromium (Cr) and nickel (Ni), which resulted in an approximately 6.5% reduction in the transformation temperature. Detecting the drop in phase transition temperature is important for using the material in higher-temperature applications.

The obtained DSC curves of the tested Ag-Ni-Cr alloy obtained during cooling (Figure 10) showed the crystallization transition temperature of the tested material in the presence of five phase transformations, where three solutions are important due to the fact that they have a relatively high transformation energy, amounting to 62 mJ, 0.9 mJ, 40.9 mJ, and 39.9 mJ, respectively (peak values of approximately 448 °C, 510 °C, and 546 °C). The lowest and highest transformation values (446 °C and 546 °C) are associated with the crystallization of impurities such as sulphur- and copper-containing compounds in a similar way to the cooling of pure silver Ag. In turn, the value of the transformation

peak (510 °C) is related to nickel (Ni) as well as the transformation of chromium and the Cr phase in the Ag alloy during cooling. The main results obtained during the analysis of the DSC test also include a demonstration that the addition of Ni and Cr reduces the melting point of the tested silver alloy—after alloying—by approximately 6.5%.

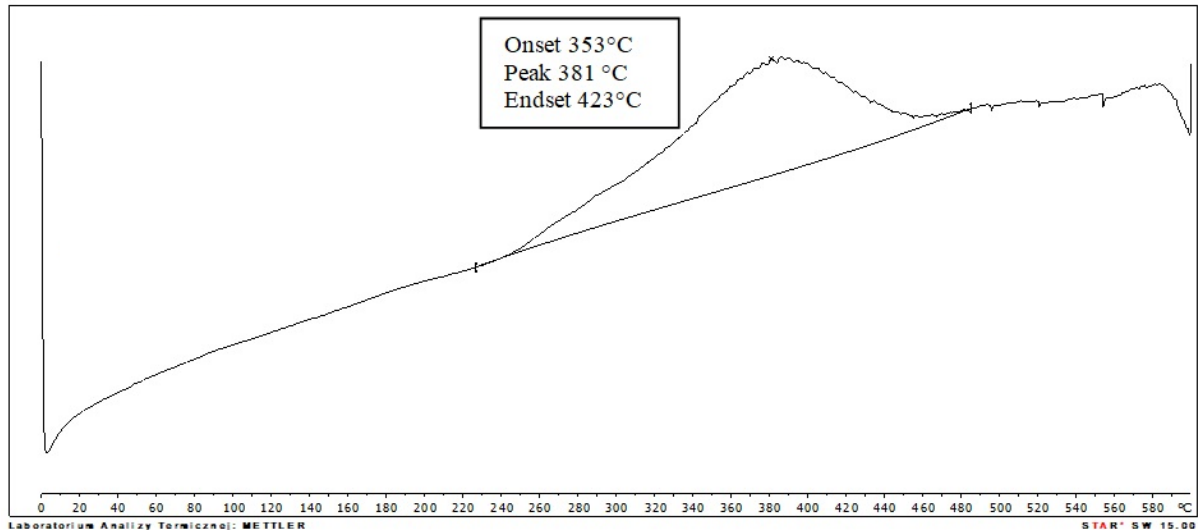


Figure 9. DSC curve of the Ag-Ni-Cr material while heating.

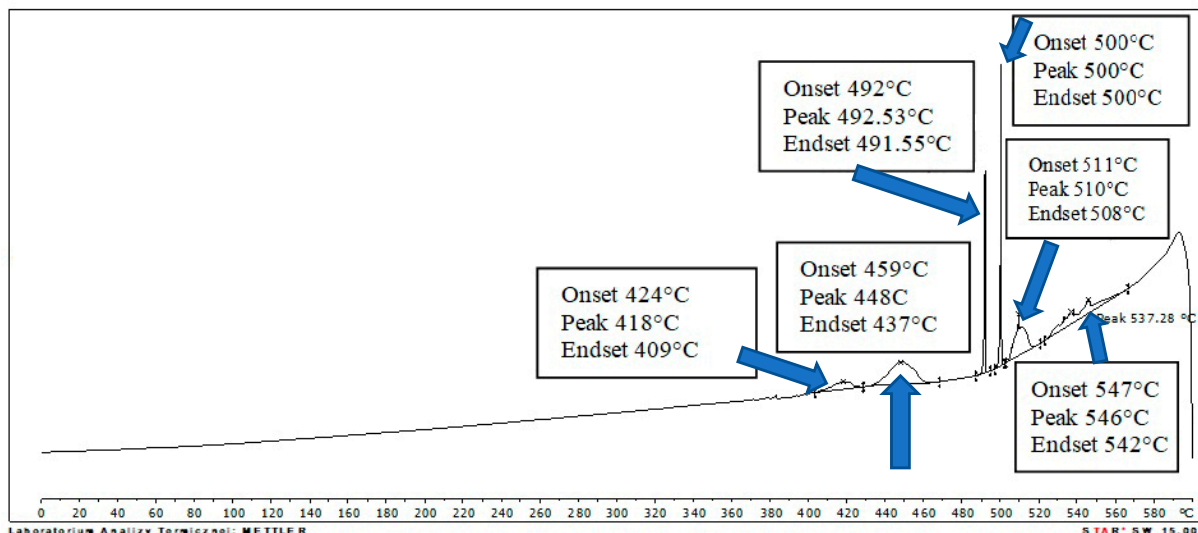


Figure 10. DSC curve of the Ag-Ni-Cr material while cooling.

An overcooling of the alloy was observed, where the temperature difference of the first phase transformation during the cooling of the pure silver (430.70 °C) compared to the silver alloy with Cr and Ni addition after laser treatment (424.96 °C) reached 5.74 °C (1.3%).

Figure 11 presents the measured hardness of the surface layer for a 3 kW laser power. The hardness of the remelted zone was significantly higher than that of the parental material. The average hardness of the obtained layer was about 92 HV0.3. The value of the Ag substrate was equal to 42 HV0.3 and increased slightly in HAZ to 46 HV0.3. It should also be noted that, based on the results of the preliminary tests, the measured hardness increased with the laser power, reaching the highest value at a 3.0 Kw laser power (Table 4). For this reason, only the results for the 3.0 Kw laser power are presented in this paper.

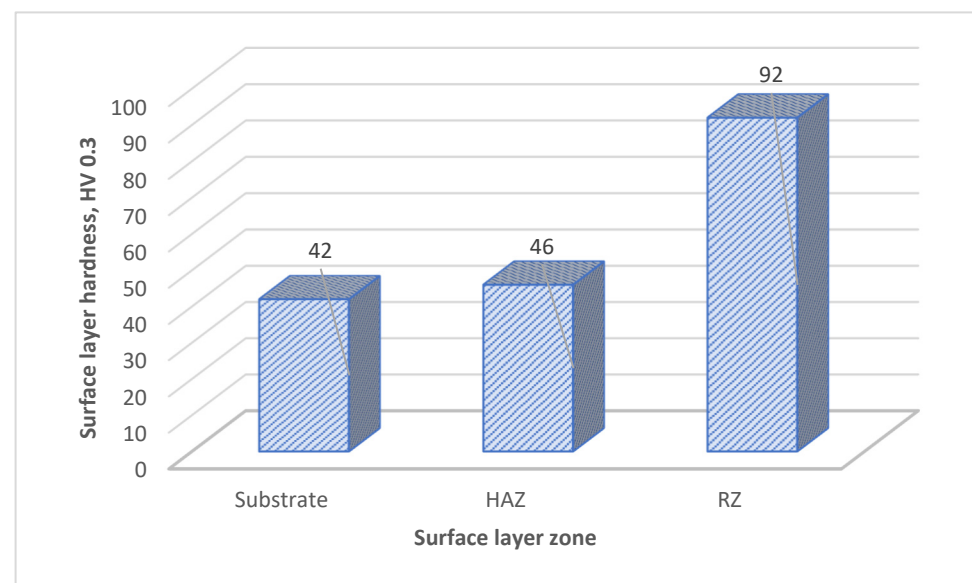


Figure 11. Surface hardness of the treated Ag surface layer, HV0.3.

Table 4. Hardness increased in the remelting zone according to the used laser power.

Hardness of the Remelting Zone, HV0.3		
2.0 kW	2.5 kW	3.0 kW
79	82	92

The applied laser surface treatment of the silver surface increased the hardness by over 100%, from 42 HV to 92 HV. This was due to the presence of hard chromium and nickel particles in the remelted surface layer, which had not dissolved in the Ag matrix but built a well-dispersed mesh of fine-graded particles.

Figure 12 displays the depth and width of the laser traces, and reveals values of 2.4 and 2.6 mm measured for the depth and width of the produced tray, respectively. It is remarkable that the parameter reaches the value of zero for a 1.5 kW laser power. Generally, with an increase in the laser beam line energy, the depth of the remelted material increases according to the increase in the laser power, with clear visible differences in the roughness of the surface after laser treatment (Figure 13).

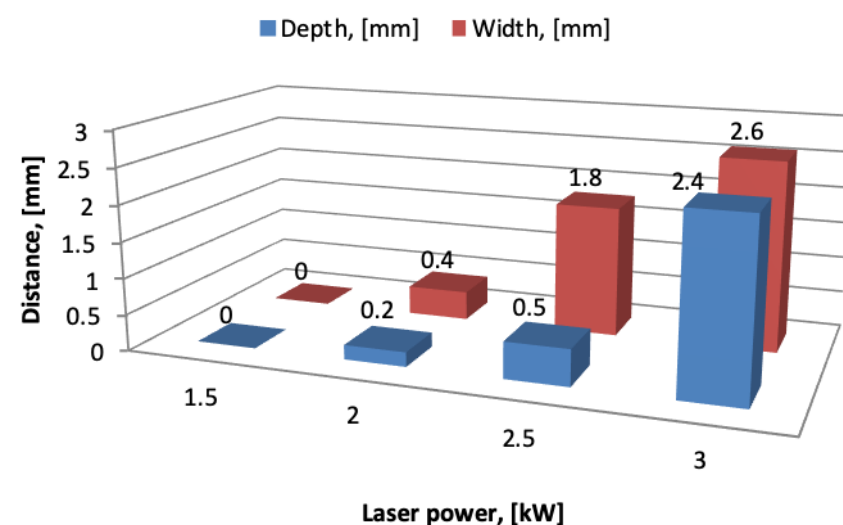


Figure 12. Depth and width of the laser trace (mm).

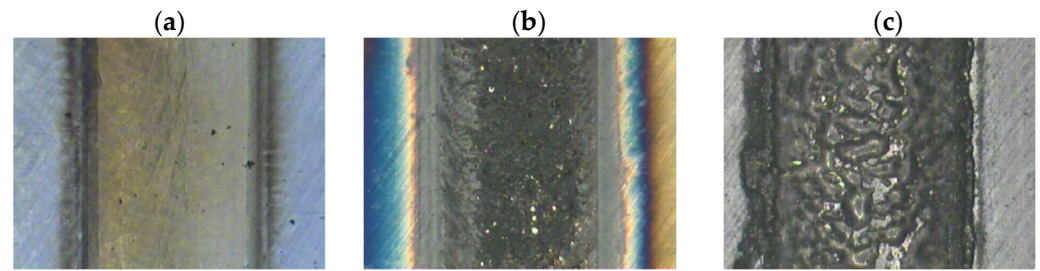


Figure 13. Surfaces of the remelted samples: (a) 2.0 kW, (b) 2.5 kW, (c) 3.0 kW laser power, with visible roughness differences.

It was found that, as the laser power used increased, the material melting depth increased. As the laser power increased, the remelted surface became smoother and flatter, without major surface defects. The presence of metal admixtures, such as the added chromium and nickel, could be confirmed in the obtained surface layer using EDS microanalysis. Metallographic examinations under scanning and light microscopes revealed a zone structure consisting of three zones. Three zones of the surface layer were found, i.e., the refusion zone (RZ), the heat-affected zone (HAZ), and a small transition zone, as well as the native material not affected by heat (Figure 14).

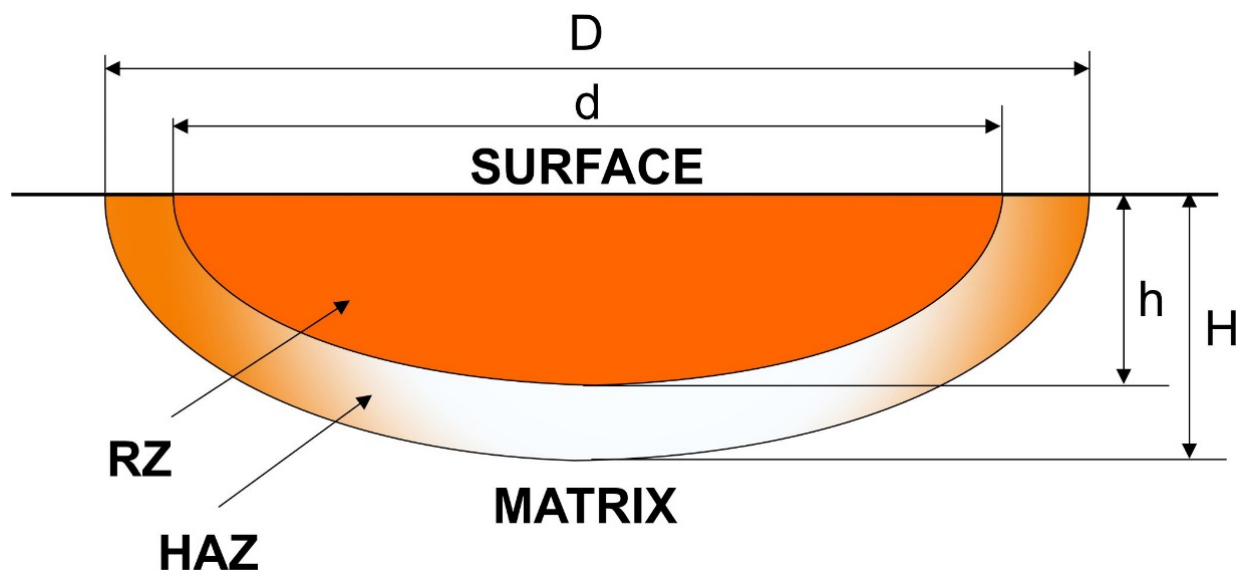


Figure 14. Cross-section of the laser-treated surface layer, presenting the schematic zone arrangement in the Ag samples: the remelting zone (RZ) and heat-affected zone (HAZ), as well as the matrix material.

The research performed and described in this article allowed for the implementation of research ideas, primarily determining the suitability of the application and use of laser surface treatment in order to improve the mechanical and operational properties of the surface of silver alloys, allowing for the creation of a surface layer characterized by better mechanical and tribological properties compared to the tested metal without surface heat treatment in the as-cast state. This is a very important achievement that could help minimize the cost of surface treatment based on traditional methods, such as heat treatment or plastic deformation. As an alternative, laser techniques can be used in combination with the enrichment of the surface layer with additional strengthening factors, such as Cr- and/or Ni-phase particles in this case, which did not undergo solution because of their low solubility as well as the short time of laser remelting.

It is difficult to find publications in the scientific literature discussing the impact of Cr and Ni additions on the structure and properties of laser-melted silver. Publications most

often discuss the impact of laser melting on the structure and properties of pure silver and 925 silver [1,30,31] and investigations concerning silver alloys with the addition of Cu, C, and W [32], or the alloy Ag-Cu [2,33]. Investigations concerning the alloy Ag-Cu-Ge have also been published [34].

It was found that the processing of Ag-Cu alloys using SLM (selective laser melting) inhibits the growth of columnar grains, which results in the refinement of the alloy [2].

In [30], after the laser alloying of pure silver powder, the presence of pores and gas trapped in the metal was found in the microstructure produced. What was particularly visible was the use of the smallest hatch distance (0.14) and the lowest laser scanning speed (650 mm/s).

The presence of irregular pores and non-melted particles was also confirmed in [34]. Moreover, it was found that, in treated pure silver and 925 silver (with the addition of Cu), the presence of pores and the grain size are the main reasons for the 400% reduction in thermal conductivity compared to silver as a cast.

As shown in [33], the density of the resulting alloy was determined according to the size of the melting pool and the thermal shrinkage. As the laser energy density increased, the density of the Ag alloy decreased due to the pores and microcracks formed, as well as thermal shrinkage. In turn, the hardness of the obtained material depended primarily on the grain size of the microstructure, as well as the obtained density of the material; therefore, obtaining a high specific density is a prerequisite for obtaining an alloy with higher hardness. Moreover, the SLM process caused grain refinement and an increase in the residual stresses of the Ag alloy, which in turn increased the Vickers hardness by three times compared with the Vickers hardness obtained during the casting process.

4. Conclusions

Tests on the functional properties of surface layers produced using a laser clearly demonstrate an increase in the hardness and abrasion resistance of the obtained surface layer with the addition of chromium and nickel metal powders. With the addition of metallic powders, the silver surface layer has the form of a quasi-composite coating, consisting of elements present in the introduced metallic powders. The powders are present in the shape of particles visible on a scanning microscope and in the dissolved state in the matrix, as confirmed by the investigation into the chemical composition. In the case of surface layers produced after alloying with powders of a 1:2 mixture (Ni-to-Cr ratio), light and electron microscopy analyses confirmed the presence of a remelted zone with the occurrence of Cr particles introduced into the silver matrix in the upper and lower zones of the surface layer.

It can be concluded that feeding the silver substrate with Cr and Ni metal powders achieved a good-quality surface, without cracks and defects, and with a hardness remarkably higher than that of the parental material. The hardness value increased with the used laser power; the highest power applied produced the highest hardness of the achieved remelted layer. Moreover, increasing the laser power increased the depth of the remelted surface layer; with increasing laser power, the surface became more regular and flatter with a visible smoothness. For the occurrence of the added metals, chromium and nickel were confirmed via EDS chemical microanalysis using a scanning and light microscope, where zones in the structure were also discovered. Three zones were discovered: the remelted zone (RZ), the heat-affected zone (HAZ), and the transition zone in between.

On the basis of DSC analysis, it was found that the addition of Cr and Ni decreased the remelting temperature of the silver matrix by approximately 6.5%. The DSC curve during the heating of the alloy reached the endothermal area connected with the melting of the eutectic at 381 °C. This is evidence of the presence of additional phases, which are the components of a eutectic. The determined thermal effect of the melting reaction was equal to approximately $+8.69 \text{ J g}^{-1}$. This is an important potential achievement of this study which could help minimize the cost of surface treatment based on traditional methods, such as heat treatment or plastic deformation. Instead of these methods, laser techniques can be

used combined with the enrichment of the surface layer with additions of strengthening factors such as Cr- and/or Ni-phase particles, which do not participate in the solution process due to their low solubility and the short time of laser remelting.

The hardness value increases with an increase in the laser power applied, so the highest applied power produces the highest hardness value in the melted layer, as in the tested case of 3.0 kW. As the laser power increased, the achieved depth of the surface also increased both the remelted zone and the heat-affected zone. Unfortunately, increasing the laser power also lead to an excessive increase in the roughness and depth of remelting, without a significant impact on the distribution of Ni and Cr particles in the Ag matrix.

From the results of this study, the following can be concluded:

1. It is possible to feed the Ni/Cr powder into a silver alloy surface layer using this type of laser device, as well as this feeding technology.
2. It is possible to use laser power in the range of 2.0 to 3.0 kW; however, the optimal laser power is 3.0 kW because of the optimal microstructure refinement and Cr phase distribution.
3. The optimal laser head speed is 0.5 m/s. For lower speeds, the remelting is too strong, causing huge roughness, whereas with laser speeds that are too high, remelting does not occur at all because of the line energy being too low.
4. Adding chromium and nickel to the silver alloy causes an overcooling of the alloy. That is, it reaches the solid-phase state at a lower temperature (547 °C) than can be seen in the phase equilibrium diagram.

It is worth underlining that the fibre laser application for metal surface treatment is a good method for shaping surface properties, making it applicable for parts used in the transportation industry where high durability, corrosion resistance, low maintenance, and lighter weight are required. New approaches also concern the application of new silver-based aluminium alloys, where these investigations could help develop materials with the required properties. Real-world applications could also concern, for example, heavy switch elements in railway transportation, but in this case, it was assumed that the obtained surface needs to be mechanically machined to ensure good surface quality in terms of factors such as smoothness and roughness, because after the laser remelting, the roughness was very high, extending beyond the measurement range for some samples.

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