



Material Properties of AISI 307 Austenitic Stainless Steel Weld Overlay Plasma-cladded onto a Ductile Iron Casting

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Abstract

The paper presents the results of material properties investigations of a weld overlay made of AISI 307 austenitic stainless steel, intended for the valve seat of sealing and draining nodes of water supply valves. A CuZn39Pb2 alloy, also used for the valve seats of these valves, served as the reference material. The AISI 307 steel weld overlay was fabricated by plasma cladding on a ductile iron substrate. The material properties investigations were carried out using the nanoindentation method. The following values were determined: Vickers hardness H_V , indentation hardness H_{IT} , indentation elastic modulus E_{IT} , reduced elastic modulus E^* , relative change in indentation depth C_{IT} , elastic deformation work $W_{elast.}$, plastic deformation work $W_{plast.}$, total mechanical work $W_{total.}$, and the elastic component of indentation work η_{IT} . The obtained results showed that the AISI 307 steel weld overlay is characterized by significantly better material properties values compared to the CuZn39Pb2 alloy. Taking into account the operating conditions of water supply valves, primarily corrosion resistance, abrasive wear resistance, and cavitation wear resistance, the obtained material properties results indicate a greater application potential for the AISI 307 steel weld overlay in the construction of sealing and draining nodes of water supply valves compared to the commonly used copper alloy.

Keywords: Plasma transferred arc (PTA), AISI 307 stainless steel, Water supply valves, Material properties

1. Introduction

Water supply valves constitute one of the fundamental infrastructure components of water distribution networks; their reliability has a significant impact on operational safety and the reduction of water losses. Cast iron valves, butterfly valves, or hydrants are among the most important components of these systems. The most critical criterion for the reliability of these elements is their tightness. During long-term operation, these components are exposed to variable mechanical loads, tribological wear processes, and corrosion processes, which can lead to a deterioration of tightness and increased water losses in distribution systems [1-2].

In commonly used valve designs, the valve seats of sealing and draining nodes are made of CuZn39Pb2 brass. This is a ring press-fitted into the cast iron body. The CuZn39Pb2 alloy is characterized by good corrosion resistance and favorable technological properties [2,3]. However, its relatively low hardness and poor resistance to abrasive wear mean that this material can undergo degradation during long-term valve operation, especially under variable load conditions in the water supply network. Additionally, this ring may loosen during operation, which can result in water leakage. All the factors mentioned above adversely affect the operational durability of the valves [3,4].

One approach to improving the operational durability of water supply valves is the use of a valve seat based on a permanent bond with the cast iron valve body in the form of a weld overlay, for



example, made of austenitic stainless steel. Austenitic stainless steels are characterized by high corrosion resistance, favorable mechanical properties, and good resistance to abrasive wear. All these advantages make austenitic stainless steel weld overlays or coatings widely used as surface layer materials for components operating under extreme conditions [5-8].

One method to evaluate the suitability of a material for operation under extreme conditions is the analysis of its material properties via nanoindentation tests. Nanoindentation is widely used in investigations of stainless steels, weld overlays, protective coatings, and multiphase materials, allowing for the evaluation of the properties of individual microstructure components while maintaining very high measurement resolution [9-15].

The aim of this work was to evaluate the material properties of the microstructure components of the CuZn39Pb2 alloy and the AISI 307 steel weld overlay. The paper analyzes parameters such as Vickers hardness HV, indentation hardness H_{IT}, indentation elastic modulus E_{IT}, reduced elastic modulus E*, relative change in indentation depth C_{IT}, elastic deformation work W_{elast.}, plastic deformation work W_{plast.}, total mechanical work W_{total.}, and the elastic component of indentation work η_{IT}. Knowledge of these parameter values will allow for the evaluation of the application potential of materials used in the construction of water supply valves, in terms of meeting the requirements for high resistance to plastic deformation, abrasive wear, corrosion, and cavitation.

2. Research Material and Methodology

The substrate material was a ductile iron casting with a ferritic-perlitic matrix, with dimensions of 140x55x8 mm. The chemical composition of the cast iron substrate is presented in Table 1.

Table 1.
Results of the chemical composition analysis of the cast iron substrate

Element content, wt. %								
C	Si	Mn	P	s	Ni	Cu	Mg	Fe
3.43	2.5	0.1	0.01	0.01	0.02	0.01	0.05	balance

The weld overlays were fabricated using AISI 307 powder. The view of these powder particles is presented in Figure 1. The powder of AISI 307 steel contains chromium, nickel, manganese, and silicon (Table 2). The powder particles have a spherical and globular shape, with sizes ranging from 12–155 μm with a share of 92%, and from 95–295 μm with a share of 8%, respectively.

The plasma cladding process was carried out using a Eutronic GAP 2501 DC device and a Comau MTR Syn 5 robot, applying the following technological parameters: current intensity I = 120 A, electric arc voltage U = 23.5 V, electrode diameter Ø = 4 mm, plasma gas - argon W = 1 l/min, shielding gas - argon W = 7 l/min, powder feed rate 20%, powder carrier gas - argon W = 2 l/min, torch travel speed v = 16 mm/min.

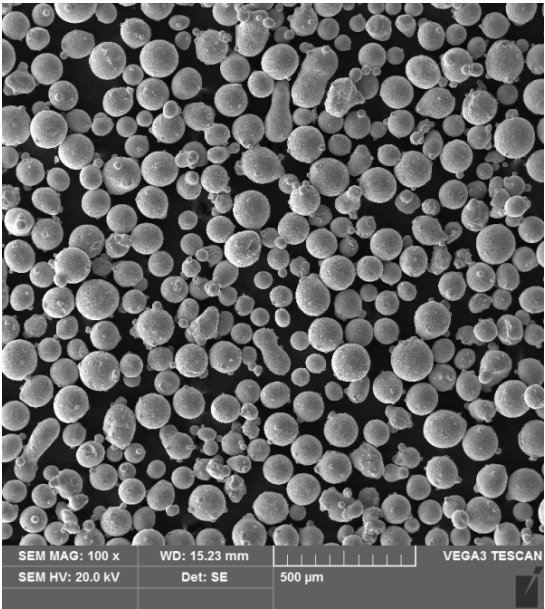


Fig. 1. View of AISI 307 powder particles

Table 2.
Results of the chemical composition analysis of the AISI 307 steel powder

Element content, wt. %				
Fe	Cr	Ni	Mn	Si
63.67	22.54	7.15	5.7	0.94

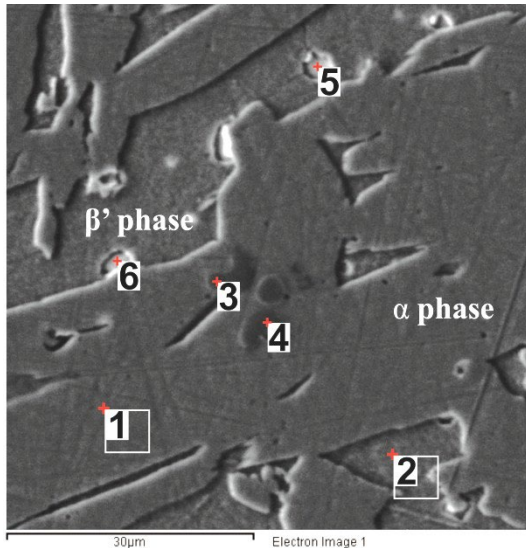
Material properties investigations were carried out on metallographic specimens prepared from samples cut from the CuZn39Pb2 ring and the AISI 307 steel weld overlay.

The evaluation of the property values was performed based on the PN-EN ISO 14577-1 standard, using a Nanoindentation Tester NHT by CSM Instruments. A diamond Berkovich indenter B-L 32 was used in the tests. The maximum load force was 10 mN, the dwell time at maximum load force was 15 s, and the loading and unloading rate of the indenter was 200 mN/min. The following material properties were determined: Vickers hardness HV, indentation hardness H_{IT}, indentation elastic modulus E_{IT}, reduced elastic modulus E*, relative change in indentation depth C_{IT}, elastic deformation work W_{elast.}, plastic deformation work W_{plast.}, total mechanical work W_{total.}, and the elastic component of indentation work η_{IT}. Each material property was determined based on three measurements, and the values reported in the table represent the arithmetic mean of these measurements.

Microstructure analysis along with X-ray chemical composition microanalysis was performed using a TESCAN Vega 3 scanning electron microscope with an INCA X-ACT (OXFORD) attachment. The microstructure investigations were conducted to identify the microstructure components of the analyzed materials, which will then be subjected to the indenter indentation test (nanoindentation).

3. Results and Analysis

An example microstructure of the CuZn39Pb2 alloy ring along with the results of the X-ray chemical composition microanalysis is presented in Figure 2.



Point	Si	Cr	Fe	Ni	Cu	Zn	Pb
1	0.00	0.00	0.00	0.00	63.28	36.72	0.00
2	0.00	0.00	0.00	0.00	55.76	44.24	0.00
3	15.41	3.10	76.10	0.82	2.65	1.93	0.00
4	15.46	3.10	75.79	1.14	2.48	2.04	0.00
5	0.00	0.00	0.00	0.00	8.00	5.89	86.10
6	0.00	0.00	0.00	0.00	7.87	5.77	86.46

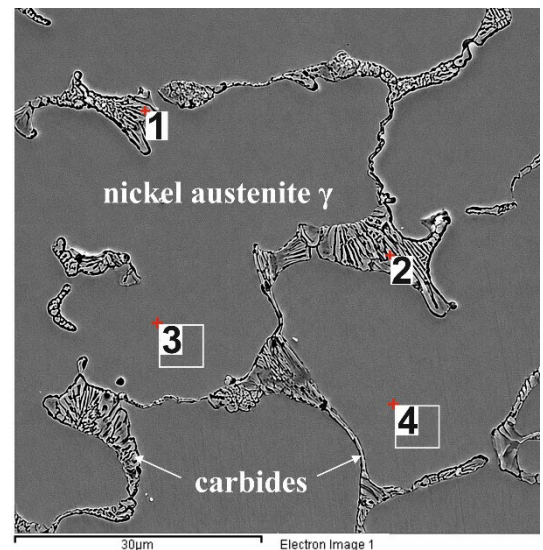
Fig. 2. Microstructure and chemical composition microanalysis results of the CuZn39Pb2 alloy

The microstructure of the CuZn39Pb2 alloy has a dual-phase character and consists of a brass matrix formed by the α and β' phases, as well as lead precipitates and a few particles of intermetallic phases. The areas with higher copper content correspond to the α phase, which is a solid solution of zinc in copper, while the areas enriched in zinc were identified as the β' phase with a composition close to the CuZn phase. Therefore, in the case of the CuZn39Pb2 alloy, nanoindentation tests will be performed within the precipitates of both these phases.

The view of the AISI 307 steel weld overlay is presented in Figure 3. An example view of the microstructure of the AISI 307 steel weld overlay along with the chemical composition is shown in Figure 4.



Fig. 3. View of the weld overlay deposited onto the cast iron substrate (a) and cross-section through the weld overlay sample (b)



Point	C	Si	Cr	Mn	Ni	Fe
1	6.60	1.38	17.60	4.31	3.25	66.83
2	6.66	1.71	14.11	4.49	3.66	69.37
3	2.99	1.53	8.82	3.08	5.09	78.49
4	2.52	1.69	8.74	3.00	5.38	78.66

Fig. 4. Microstructure and chemical composition of the AISI 307 steel weld overlay

Analysis of the SEM images and chemical composition showed that the AISI 307 steel weld overlay consists of nickel austenite γ grains rich in iron, chromium, nickel, manganese, and silicon. At the grain boundaries, a eutectic occurs (austenite γ + carbides), whose precipitates are characterized by an increased content of chromium and iron. Therefore, in the case of the AISI 307 weld overlay, nanoindentation tests were performed for both identified components of its microstructure.

The displacement of the indenter tip during its loading and unloading in the nanoindentation test of the CuZn39Pb2 alloy microstructure components and the AISI 307 steel weld overlay is presented in Figures 5 and 6.

The material properties values determined during nanoindentation tests of the CuZn39Pb2 alloy microstructure

components and the AISI 307 steel weld overlay are presented in Table 3.

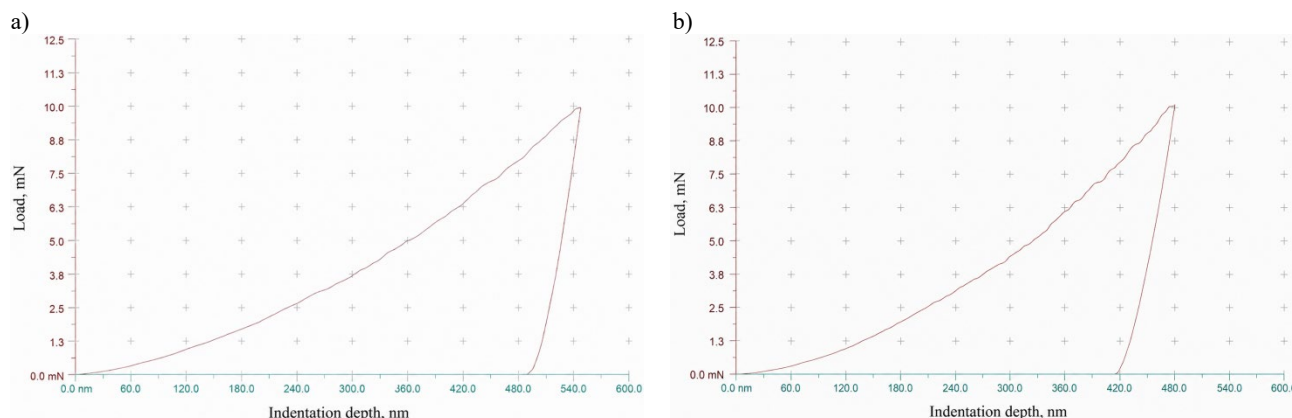


Fig. 5. Indenter tip displacement during its loading and unloading in the nanoindentation test of the CuZn39Pb2 alloy microstructure components; a) α phase, b) β' phase

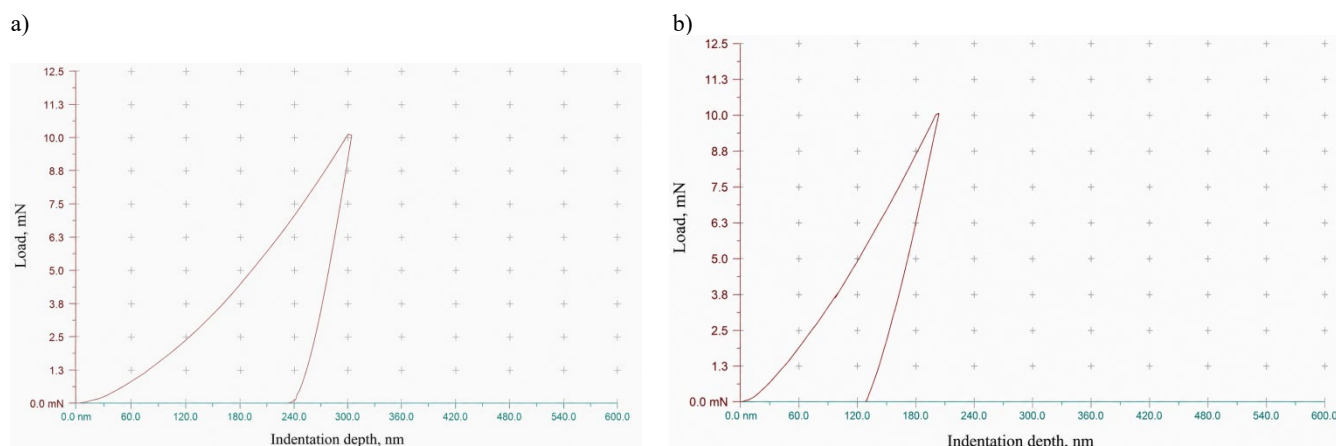


Fig. 6. Indenter tip displacement during its loading and unloading in the nanoindentation test of the AISI 307 steel weld overlay microstructure components; a) nickel austenite γ , b) carbide precipitates

Table 3.

Material properties values of the CuZn39Pb2 alloy and AISI 307 steel weld overlay microstructure components

Material	Microstructure component	Material property values								
		HV	H_{IT} , MPa	E_{IT} , GPa	E^* , GPa	C_{IT} , %	$W_{elast.}$, pJ	$W_{plast.}$, pJ	$W_{total.}$, pJ	η_{IT} , %
CuZn39Pb2 alloy	α phase	140.98	1522.30	88.05	96.76	0.82	220.58	1860.17	2080.74	10.60
	β' phase	191.02	2062.60	88.08	96.79	1.17	255.05	1520.69	1775.74	14.36
AISI 307 steel weld overlay	nickel austenite γ	480.11	5184.10	142.74	156.85	1.79	270.95	955.34	1226.28	22.09
	carbides	1221.80	13193.00	183.55	201.70	1.56	335.39	486.46	821.85	40.81

The obtained nanoindentation test results indicate clear differences in the material property values between the microstructure components of the CuZn39Pb2 alloy and the AISI 307 steel weld overlay. From the standpoint of evaluating plastic deformation resistance, the microstructure of the AISI 307 steel weld overlay exhibits significantly better resistance, as its HV hardness and indentation hardness H_{IT} values are several times

higher compared to the CuZn39Pb2 alloy. The high hardness of the weld overlay microstructure components, especially the carbides, can effectively limit micro-cutting and plastic deformation processes during the operation of the valve's sealing and draining node valve seat.

An important element in evaluating plastic deformation resistance is the analysis of the indenter loading and unloading

curves (Figs. 5 and 6) from the perspective of the contribution of individual components to the total mechanical work W_{total} . In the case of the CuZn39Pb2 alloy microstructure components, the plastic deformation work $W_{plas.}$ has a larger share, whereas for the AISI 307 steel weld overlay, the elastic deformation work W_{elast} shows a greater contribution. This is confirmed by the value of the η_{IT} parameter, which represents the elastic component of the indentation work.

The superior elastic properties of the AISI 307 steel weld overlay, meaning high stiffness, are further confirmed by the higher values of the indentation elastic modulus E_{IT} and the reduced elastic modulus E^* compared to the CuZn39Pb2 alloy.

Regarding the C_{IT} parameter, i.e., the relative change in indentation depth, which serves as a measure of the material's creep resistance, both analyzed materials are characterized by a relatively low value of this parameter, at the level of 1–2%.

4. Conclusions

Due to its plastic deformation resistance, elastic properties, and stiffness, the AISI 307 steel weld overlay is characterized by a combination of better material properties values compared to the CuZn39Pb2 alloy.

Taking into account the operating conditions of water supply valves, which primarily involve requirements for abrasive wear resistance, and cavitation wear resistance, the obtained material properties values indicate that the weld overlay made of AISI 307 steel has a greater application potential in the construction of sealing and draining nodes of water supply valves than commonly used copper alloys.

Nanoindentation tests allow for the determination of material properties that are useful in the material selection process in terms of meeting the required criteria resulting from future operating conditions.

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