DOI: https://doi.org/10.26628/wtr.v93i2.1134

PRZEGLĄD SPAWALNICTWA
Welding
TECHNOLOGY REVIEW

Original Article

Influence of austenitic interlayer on the properties of stellite padding welds after impact-hardening

Weronika Henzler[1], Mateusz Sawa[1], Przemysław Trębicki[1], Mirosław Szala[2]*, and Grzegorz Winiarski

[1] Students Research Group of Materials Technology, Department of Materials Engineering, Lublin University of Technology, Lublin, Poland; weronika.henzler@pollub.edu.pl (W.H.)
[2] Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland; m.szala@pollub.pl
[3] Department of Computer Modelling and Metal Forming Technologies, Faculty of Mechanical Engineering, Lublin University of Technology, Poland; g.winiarski@pollub.pl (G.W.)
* Correspondence: m.szala@pollub.pl; (M.Sz.)

Received: 26.02.2021; Accepted: 21.03.2021

Abstract: Stellites (Co-Cr-W-C) are the specific group of coating materials used for surface modification of the engineering materials and for remanufacturing. The aim of the paper was to research the influence of austenitic (308LSi) interlayer on hardening rate of stellite 1 and stellite 6 after impact hardening. The samples have been cladded by TIG welding method with interlayer and without. Before impact hardening the samples have been visually and penetrant non-destructive tested. The samples after impact hardening have been tested by metallographic and Vickers hardness methods. The highest impact hardening effect have been revealed for coatings deposited with interlayer. The highest impact hardening effect was achieved for the padding welds produced with the interlayer, i.e. for stellite 1 (increased by 29.8%) and stellite 6 (increased by 42.7%). The hardening of the coating samples deposited without interlayer was lower and amounted to stellite 1 (increased by 13.7%) and stellite 6 (increased by 29.8%) respectively. The highest hardness values were obtained for impact-hardened cladded welds without the use of an interlayer (stellite 1; 790 HV0.1 and stellite 6; 732 HV0.1). The use of an interlayer reduces the hardness of the stellite coating while increasing the susceptibility to hardening and plastic deformation of the produced coating.

Keywords: stellite; TIG cladding; interlayer; hardness; impact hardening; spring hammer

Introduction

The improvement of the operational properties of metal elements can be obtained by using various surface engineering methods, such as coatings thermal spraying [1÷3], thermal or thermo-chemical treatment [4,5], ion implantation [6], surface treatment by shot peening [7,8] or surfacing [9÷11]. Welding methods produce layers aimed mainly at increasing wear resistance, ensuring high corrosion resistance and increased resistance to temperature or impact loads [12÷15]. The above-mentioned properties are guaranteed by padding welds made of additional materials based on cobalt, i.e. stellites. Stellite are a group of cobalt-based alloys containing chromium, tungsten, carbon, iron, molybdenum and other elements. Traditional Co-Cr-W-C stellites usually contain 35÷55% Co, 25÷33% Cr, 10÷25% W, 1÷3% C, and their microstructure is composed of cobalt austenite containing carbides [15÷18]. Stellite can be welded on elements subject to impact loads, such as tools used in plastic working [19,20]. Stellites' hardness is up to 62 HRC. The morphology and the carbide content affect the hardness of the stellite. Despite the fact that stellites are plastically deformable materials [17], thanks to the plastic deformation-induced structural transformation in the cobalt austenite network, they have the ability to accumulate impact loads, which significantly extends the scope of their applications. They are used for the production of components used in a demanding work environment, such as components of internal combustion engines (high-temperature corrosion, mechanical loads, abrasive wear and fatigue processes) [12,13,16,21].

One of the most frequently used cobalt alloys are the following grades: stellite 1 and stellite 6. According to the literature [12,22,23], stellite 1 is an alloy for surfacing, which has a high resistance to abrasion and corrosion. Stellite 1 retains high hardness at temperatures in excess of 760 °C. The microstructure of Stellite

1 consists of a high proportion of wear-resistant primary carbides. This makes the alloy well-suited for applications requiring high abrasive wear resistance. It is used in applications such as pump shafts, grinding wheels, bearing sleeves, extruder's screws. In contrast, stellite 6 is the most widely used cobalt-based wear resistant alloy as it exhibits versatile performance characteristics. It is recognized as the basic industrial alloy with excellent resistance to mechanical wear and corrosion and a high hardness at 500 °C. It also has good impact resistance and cavitation erosion. Stellite 6 is ideal for various surfacing processes and the padding welds can be machined. The most common applications of this alloy are valve seats and gates, pump shafts and bearings, erosion discs and rolling pairs [12,22,23].

As is commonly known, the operational properties of pad welded coatings depend to a large extent on the proposed surfacing technology, the dilution which represents the contribution from base material to weld metal, and the chemical composition of the parent and coating material. On the other hand, the surfacing parameters have a decisive influence on the degree of dilution. The average dilution in the pad weld in manual arc welding is 25 to 40%. Based on the literature data [12,24] it is known that the use of an interlayer may have a beneficial effect on the properties of padding welds. The buffer layer, depending on the thickness, chemical composition of the applied material, and the dilution which, affects the hardness of the padding weld. Unfortunately, there is little information in the literature about the impact of the use of an interlayer on the hardness of impact-hardened padding welds. There are particularly few works describing the issue of stellite strengthening. Therefore, the aim of the study was to assess the influence of the austenitic interlayer (308LSi) on the change of hardness and the degree of hardening of stellite's padding welds (stellite 1 and stellite 6) subjected to impact loads. The work presents a comparative analysis of padding welds produced on a steel substrate without and with the use of a stainless steel weld metal interlayer (Fe-Cr-Ni) strengthened on a spring hammer.

Materials and methodology of the research

The scope of experimental research

The planned experiment consisted of the following stages:

- surfacing of stellite layers with an austenitic buffer layer and directly,
- visual and penetration tests of the produced padding welds,
- impact hardening of padding welds,
- preparation of metallographic specimens of samples in a state after surfacing and after hardening on a spring hammer (dedicated for plastic working processes),
- metallographic tests and HV0.1 hardness measurements,
- analysis of the results in terms of the strain hardening of padding welds and the identification of the influence of the interlayer on the hardness of the padding welds.

The course of the experiment

The TIG surfacing process was conducted with a direct current of 100÷120 A, in the PA position, with negative polarity, argon of purity class 4.8 was used as the shielding gas. One layer of padding welds made of stellite 1 and stellite 6 (without interlayer) was applied to a steel substrate (S235JR) with dimensions of 5 x 20 x 150 mm (without the use of an interlayer), and another two samples were welded in two layers, austenitic weld metal (308LSi) was applied as the base layer, and the second layer was made of stellite 1 or stellite 6, the designations of eight tested samples are included in table I. EL-Co 1 and EL-Co 6 rods (equivalents of stellite 1 and stellite 6) were used for surfacing. The nominal composition of the stellite and the buffer layer is presented in table II and table III. Structural steel S235JR was selected as the substrate for the stellite padding welds, which is characterized by relatively high plasticity and low susceptibility to hardening during the welding process. This choice minimized the influence of the substrate on the obtained results of impact hardening of the stellite padding welds.

Table I. Samples characterisation

Designation of samples/processing conditions		Substrate	Interlayer	Surfaced coating
as-welded	**hammered**			
1-aw	1-H	S235JR	–	EL-Co 1
6-aw	6-H	S235JR	–	EL-Co 6
1s-aw	1s-H	S235JR	308LSi	EL-Co 1
6s-aw	6s-H	S235JR	308LSi	EL-Co 6

After the surfacing, visual tests were carried out in accordance with ISO 17637 (Non-destructive testing of welds – Visual testing of fusion-welded joints, 2016) and penetration tests of the produced surfaced layers in accordance with ISO 3452-2 (Non-destructive testing – Penetrant testing – Part 2: Testing of penetrant materials, 2013). The produced padding welds were subjected to impact hardening on a spring hammer type MR 50 [25] (dedicated for plastic working processes) with a compression of approx. 30%. The degree of compression Z was calculated as the ratio of the initial height of the samples (F_0) to the height of the samples after impact hardening (F_1) according to the equation (1):

$$Z = \frac{F_0 - F_1}{F_0} * 100\% \tag{1}$$

Table II. Nominal properties and chemical composition of Co-based fillers [22,23,26]

Grade	Chemical composition, wt.%					Mechanical properties			
	Cr	W	C	Co	Other	Hardness HRC	Hardness HV	Density, g/cm³	Melting temperature, °C
Stellite 1, EL-Co 1	30	13	2.5	base	Ni, Fe, Si, Mn, Mo	50÷58	512÷654	8.69	1190÷1345
Stellite 6, EL-Co 6	28	4	1.1	base		36÷45	354÷446	8.44	1285÷1410

Table III. Chemical composition and mechanical properties of austenitic interlayer material 308LSi [27]

Chemical composition, wt.%						Re, N/mm²	Rm, N/mm²	A5, %
Fe	C	Si	Mn	Cr	Ni			
rest	<0.03	0.80	1.8	20	10	480	625	37

Microstructure and hardness tests

Microscopic and macroscopic metallographic examinations were carried out on etched specimens in accordance with ISO 17639 (Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds, 2003). For this purpose, cross-sections were prepared, ground, polished and finally etched with aqua regia (hydrochloric acid + nitric acid in a 3:1 volume ratio). The microstructure examination was carried out using a NIKON MA200 metallographic microscope. Based on the photographs of the non-etched specimens, the dilution of the padding welds *D* was calculated (2) [28].

$$D = \frac{A_w}{(A_w + A_n)}\% \tag{2}$$

Hardness was measured by the Vickers method according to EN ISO 5173:2010 on the HV0.1 scale. The FutureTech FM800 micro hardness tester was used for hardness measurements. The measurement was carried out on the cross-section of the padding welds, along the path (the distance between the indentations approx. 1 mm) in the direction from the padding weld's surface to the steel substrate in accordance with the diagram given in figure 1. 6÷10 indentations were made in each layer. The hardness was measured on the cross sections of the padding welds before and after impact treatment. The degree of hardening of impact-treated padding welds was calculated as the ratio of the average hardness value of the hardened coatings to the hardness of the coatings in the as-welded condition.

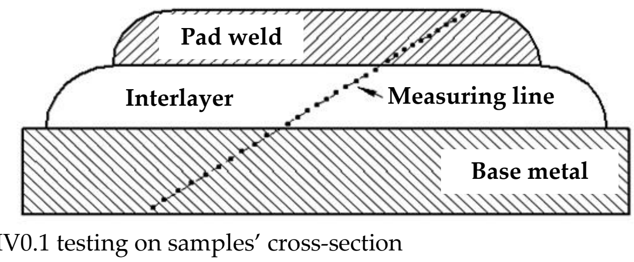


Fig. 1. Scheme of hardness HV0.1 testing on samples' cross-section

Research results and their analysis

Characteristics of the tested samples

The cross-sections of the tested padding welds after impact hardening are shown in figure 2, while the microstructure of selected stellite welds is shown in figure 3. The visual and penetration tests carried out allow to state that the padding welds did not show any discontinuities and cracks. The degree of mixing of the padding welds was in the range of 23÷34%. TIG padding welds are characterized by a relatively high degree of mixing, which is consistent with the literature data [24,29].

Macroscopic examinations of the cross sections of padding welds before and after impact hardening were carried out. It was found that the impact loads cause cracking of the stellite 1 layer (Fig. 2a without interlayer). In the case of samples with the 1s-aw interlayer, a porosity was identified at the boundary of the interlayer with the coating, which caused a crack in the sample subjected to impact hardening 1s-H (Fig. 2c). In the case of samples surfaced with stellite 6, cracking of the padding weld 6-aw (Fig. 2b) subjected to impact hardening (6-H) is identified. On the other hand, the use of an interlayer effectively increases the plastic properties of the padding weld. In the case of the crushed 6s-aw sample, no cracks were identified (Fig. 2d).

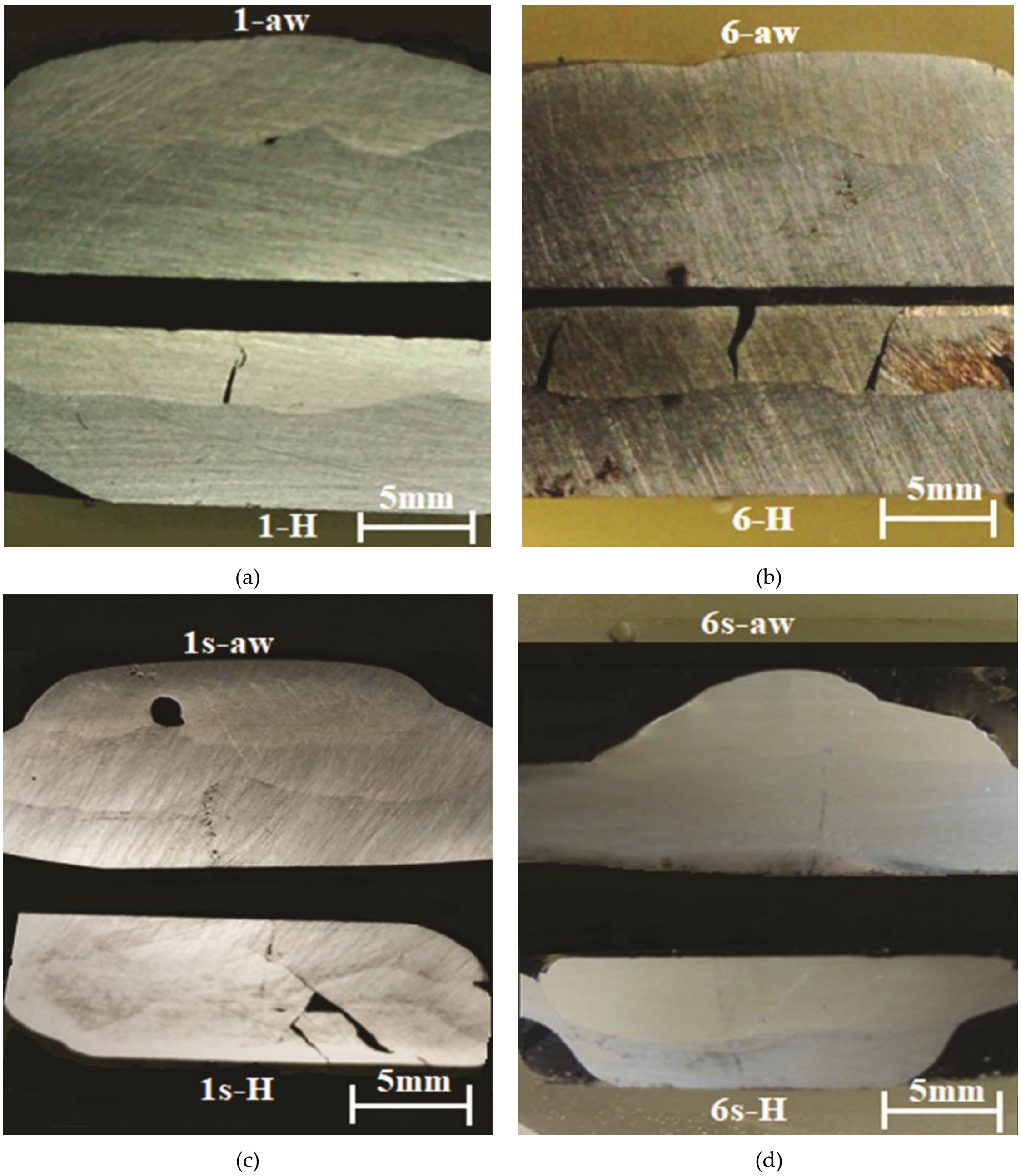
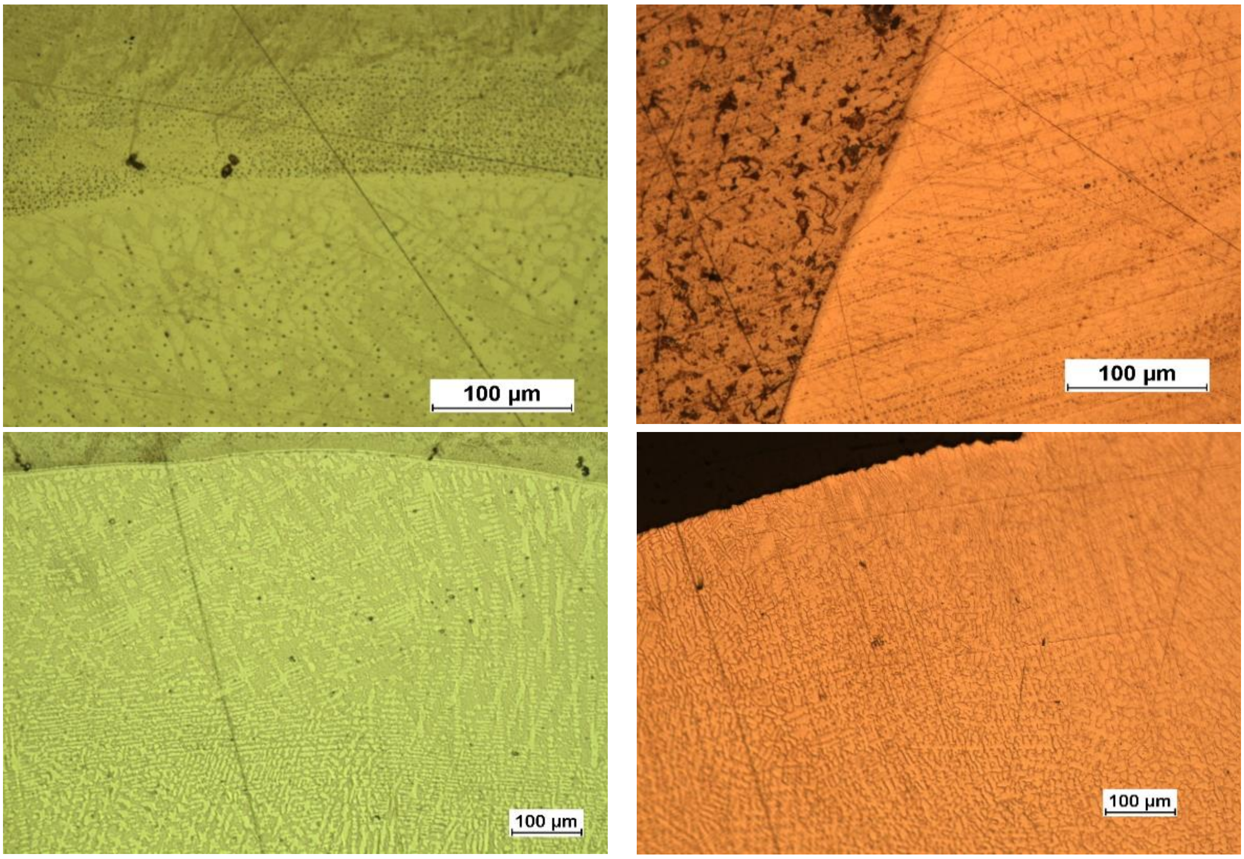


Fig. 2. View of as-welded (aw) and impact hardened (H) samples in cross-section: a) sample 1-aw & 1-H (cladded with Stellite 1 without interlayer); (b) sample 6-aw & 6-H (cladded with Stellite 6 without interlayer); (c) sample 1s-aw & 1s-H (cladded with Stellite 1 with interlayer); (d) sample 6s-aw & 6s-H (cladded with Stellite 6 with interlayer)

The microstructure of padding welds has a dendritic structure (Fig. 3). The dendritic region consists of cobalt austenite strengthened by elements such as chromium, tungsten, and admixtures of iron, manganese and silicon. Dendrites grow from the fusion line towards the padding weld's axis. Interdendritic eutectics containing carbides are rich in tungsten and chromium. The microstructure of stellite 1 consists of primary carbides identified in the interdendritic eutectics and cobalt austenite. Surfacing with the interlayer does not change the microstructure of the near-surface layer of the stellite coating. The structure of stellite 6 consists of finer grains as compared to stellite 1. Grains of stellite 6 have an oval shape and in stellite 1 they are more elongated, which results from the method of crystallization and is related to the difference in the chemical composition of the tested stellite. The results of the analysis of the microstructure of the stellite padding welds are consistent with the data reported in the literature [16,17,30].



(a) (b)

Fig. 3. Microstructure of stellite pad welds: (a) 1s-aw: 308LSi interlayer + EL-Co 1 pad weld; (b) 6-aw: S235JR substrate + EL-Co 6 pad weld

Hardness and degree of impact hardening

The results of hardness measurements of eight tested stellite layers are presented in figure 4, while figure 5 shows the degree of strengthening of the padding welds. Figure 6 shows changes in hardness of padding welds with an interlayer. The hardness of stellite after surfacing is similar to the data reported in the literature [17,31]. By analyzing the results of measurements of the hardness of the stellite layers (Fig. 4), it was found that all samples subjected to impact hardening have a higher hardness than the samples after surfacing (as-welded). Sample 1 was characterized by the highest hardness of about 694 HV0.1. The hardness of the 6-aw samples was about 559 HV0.1. The results of the surfaced samples with the austenitic interlayer (1s-aw, 6s-aw) were below the value of 500 HV0.1. The 6s-aw sample was characterized by the lowest hardness, approx. 425 HV0.1. In the case of samples surfaced with stellite 6 (6-aw, 6s-aw) subjected to impact hardening, an increase in hardness of at least 200 HV0.1 was observed. Sample (1-H) showed the lowest increase in microhardness. For sample 1-aw, a much greater increase in hardness was obtained. It may be related to the much higher content of carbide-forming elements (W, Cr and C) that affect the formation of primary carbides of considerable size and higher hardness than in stellite 6 [31]. These carbides are characterized by a much higher hardness than the plastic cobalt matrix of the padding weld, which results in a high average hardness of the padding weld (694 HV0.1) and a wide spread of recorded hardness values.

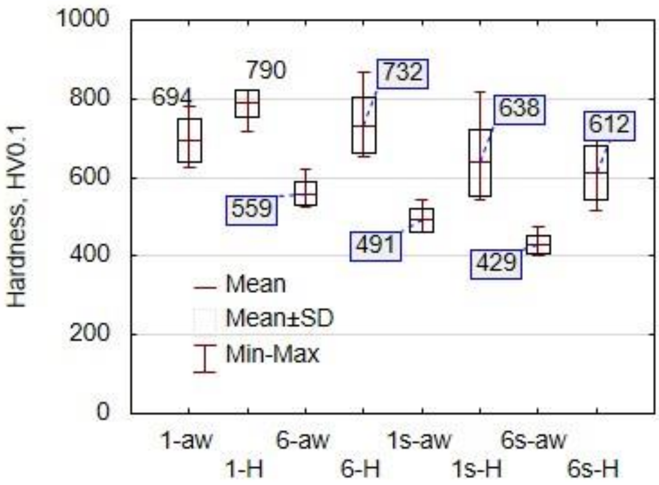


Fig. 4. Hardness of stellite coatings as-welded (aw) and after impact hardening (H)

Both in the samples after before and after impact hardening, a decrease in hardness with increasing distance from the surface of the samples is visible (Fig. 5). This is due to the change in the dilution of the stellite material, which results in a reduction in hardness, to the value of the hardness of the interlayer material (approx. 350 HV0.1 and the substrate approx. 150 HV0.1). The samples (1s-aw and 6s-aw), which were made with the interlayer, were characterized by low hardness values (491 HV0.1 and 429 HV0.1), but at the same time were subject to the highest impact hardening (Fig. 6). The hardening of the stellite 1 and 6 surfaced with the interlayer was respectively 29.8% and 42.7%, while the hardening of the samples surfaced without the interlayer was lower and amounted to 13.7% and 29.8% respectively (Fig. 6). The test results confirm that stellite 6 is more susceptible to hardening than stellite 1.

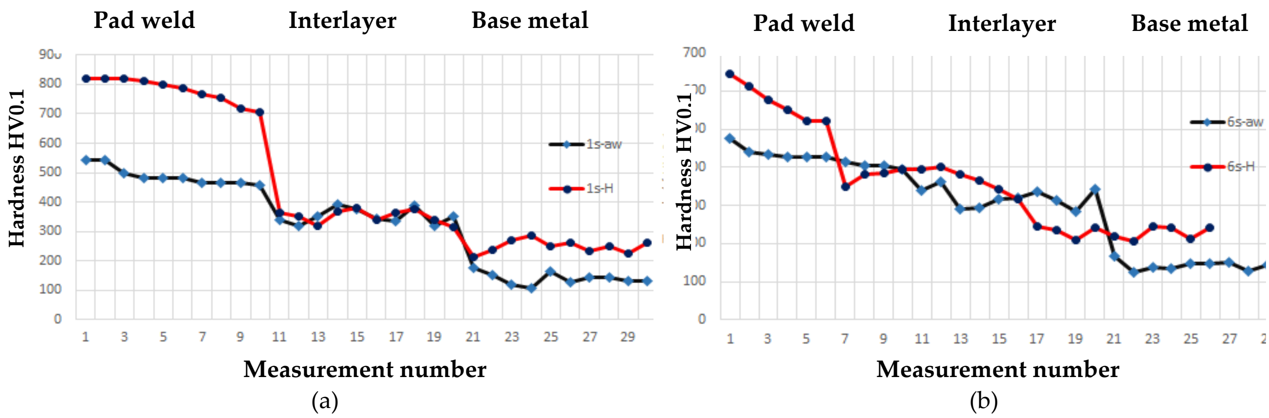


Fig. 5. Hardness HV0,1 distribution of pad weld, interlayer and substrate in cross-section and after impact hardening: a) samples: 1s-aw & 1s-H); (b) samples: 6s-aw and 6s-H

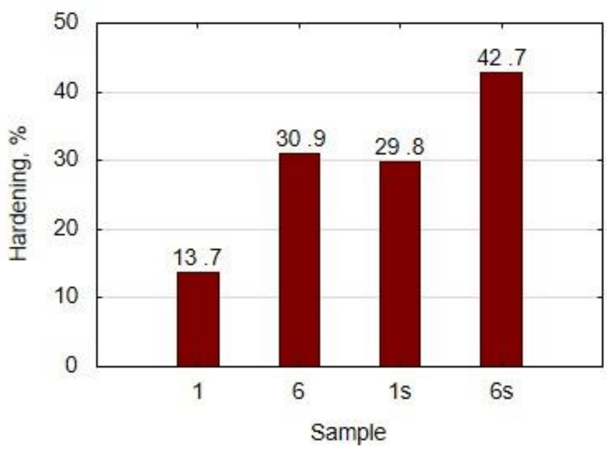


Fig. 6. Changes in sample hardness due to impact hardening, samples 1 and 6 – without interlayer, samples 1s and 6s – with interlayer

Summary and Conclusions

The aim of the work was to investigate the effect of austenitic weld metal interlayer on the hardness of stellite padding welds subjected to impact loads (impact hardening). The analysis of the conducted research allows for the following conclusions:

- The highest hardness was obtained for stellite surfaced without interlayer, i.e. for stellite 1 the hardness was 694 HV0.1, while the hardness of stellite 6 was 599 HV0.1.
- The austenitic interlayer results in a reduction of the hardness of the layer surfaced with stellite 1 to the value of 491 HV0.1 and the layer surfaced with stellite 6 to the level of 429 HV0.1.
- The impact loads applied on the spring hammer increase the hardness of the stellite coatings. Stellite coatings welded directly on steel and subjected to impact hardening are characterized by higher hardness values (stellite 1-H; 790HV and stellite 6-H; 732HV) than stellite coatings welded with an austenitic buffer layer: stellite 1s-H; 638HV and 6s-H stellite; 612HV.
- The hardening of stellite 1 and 6 surfaced with the austenitic interlayer was respectively 29.8% and 42.7%, while the hardening of the samples surfaced without interlayer was lower, respectively 13.7% and 29.8%. Stellite 6, compared to stellite 1, shows greater hardening as a result of impact loads. In the case of stellite 1 (1-H, 1s-H) layers, the microhardness after the impact test increased by 60÷160 HV, while in the case of stellite 6 (6-H, 6s-H) by 200÷380 HV.
- The structure of the tested stellite 1 and 6 is dendritic and consists of a solid cobalt austenite solution and interdendritic eutectics rich in carbide precipitates, in the case of stellite 1, primary carbides are also identified.

Author Contributions: conceptualization, W.H., M.S., P.T. and M.Sz.; methodology, W.H., M.S., P.T. and M.Sz.; formal analysis, W.H., M.S., P.T. and M.Sz.; investigation, W.H., M.S., P.T., M.Sz. and G.W.; writing—original draft preparation, W.H. and M.Sz.; writing—review and editing, W.H. and M.Sz.; supervision, M.Sz.; project administration, M.Sz.; funding acquisition, M.Sz.

Funding: The project/research was financed in the framework of the project Lublin University of Technology-Regional Excellence Initiative, funded by the Polish Ministry of Science and Higher Education (contract no. 030/RID/2018/19), in frame of students research grant no. Z12.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] Park C.-K., Lee J.-H., Kang N.-H., Chun E.-J., Correlation between Microstructure and Tribological Properties of Laser Surface Heat-Treated Stellite Coatings. *Coatings* Internet, 2020, Vol. 10(5), 433.

[2] Simunovic K., Havrlisan S., Saric T., Vukelic D., Modeling and Optimization in Investigating Thermally Sprayed Ni-Based Self-Fluxing Alloy Coatings: A Review. *Materials*, 2020, Vol. 13(20), 4584.

[3] Singh J., Kumar S., Mohapatra S.K., An erosion and corrosion study on thermally sprayed WC-Co-Cr powder synergized with Mo2C/Y2O3/ZrO2 feedstock powders. *Wear*, 2019, Vol. 438–439. https://doi.org/10.1016/j.wear.2019.01.082

[4] Kaszuba M., Widomski P., Białucki P., Lange A., Boryczko B., Walczak M., Properties of new-generation hybrid layers combining hardfacing and nitriding dedicated to improvement in forging tools' durability. *Archives of Civil and Mechanical Engineering*, 2020, Vol. 20(3), 78.

[5] Wierzchoń T., Burakowski T., Inżynieria powierzchni metali.*WNT*, 1995. 556 s.

[6] Budzyński P., Kamiński M., Turek M., Wiertel M., Impact of nitrogen and manganese ion implantation on the tribological properties of Stellite 6 alloy. *Wear*, 2020, Vol. 456–457, 203360.

[7] Żebrowski R., Walczak M., Effect of the Shot Peening on Surface Properties and Tribological Performance of Ti-6Al-4V Alloy Produced by Means of DMLS Technology. *Arch. of Metallurgy and Materials*, 2019, Vol. 64(1), 377–83.

[8] Macek W., Szala M., Kowalski M., Gargasas J., Rehmus-Forc A., Deptuła A., Shot peening intensity effect on bending fatigue strength of S235, S355 and P460 structural steels. *IOP Conference Series: Materials Science and Engineering*, 2019, Vol. 710, 012035.

[9] Łatka L., Biskup P., Development in PTA Surface Modifications – A Review. *Advances in Materials Science*, 2020, Vol. 20(2), 39–53.

[10] Mendez P.F., Barnes N., Bell K., Borle S.D., Gajapathi S.S., Guest S.D., i in., Welding processes for wear resistant overlays. *Journal of Manufacturing Processes*, 2014, Vol. 16(1), 4–25.

[11] Czupryński A., Adamiak M., Bayraktar E., Wyględacz B., Comparison of tribological properties and structure of coatings produced in powder flame spraying process on grey cast iron. *Weld. Tech. Rev.*, 2020, Vol. 92(3), 7–21.

[12] Klimpel A., Napawanie i natryskiwanie cieplne: technologie.*WNT*, 2009. 470 s.
[13] Bazychowska S., Smoleńska H., Kończewicz W., The Impact of Material Selection on Durability of Exhaust Valve Faces of a Ship Engine – A Case Study. *Advances in Science and Technology Research Journal*, 2020, Vol. 14(3), 165–74.
[14] Bartkowski D., Matysiak W., Wojtko K., Stellite-6 surface layers reinforced with hard and refractory WC particles produced on steel for metal forming. *IOP Conference Series: Materials Science and Engineering*, 2018, Vol. 393, 012093.
[15] Hattori S., Mikami N., Cavitation erosion resistance of stellite alloy weld overlays. *Wear* Internet, 2009, Vol. 267(11), 1954–60.
[16] Chmielewski T., Golański D., Napawanie brązu berylowego stellitem metodą MCAW. *Welding Technology Review*, 2011, Vol. 83(10). https://doi.org/10.26628/wtr.v83i10.464
[17] Falqueto L.E., Butkus D.J., De Mello J.D.B., Bozzi A.C., Scandian C., Sliding wear of cobalt-based alloys used in rolling seamless tubes. *Wear*, 2017, Vol. 376–377, 1739–46.
[18] Szala M., Hejwowski T., Improvement of cavitation erosion resistance of metal alloys by pad welding of coatings. *Przegląd Spawalnictwa - Welding Technology Review*, 2015, Vol. 87(9), 56–60.
[19] Foster J., Cullen C., Fitzpatrick S., Payne G., Hall L., Marashi J., Remanufacture of hot forging tools and dies using laser metal deposition with powder and a hard-facing alloy Stellite 21®. *Journ. of Remanuf.*, 2019, Vol. 9(3), 189–203.
[20] G.p. R., M. K., Bakshi S.R., Hardfacing of AISI H13 tool steel with Stellite 21 alloy using cold metal transfer welding process. *Surface and Coatings Technology*, 2017, Vol. 326, 63–71.
[21] Szala M., Walczak M., Cavitation erosion and sliding wear resistance of HVOF coatings. *Welding Technology Review*, 2018, Vol. 90(10). https://doi.org/10.26628/wtr.v90i10.964
[22] Materiały spawalnicze : MOST EL-Co 6 - drut spawalniczy.Materiały spawalnicze: www.rywal.com.pl.
[23] Materiały spawalnicze : MOST EL-Co 1 - drut spawalniczy.Materiały spawalnicze: www.rywal.com.pl.
[24] K. Ferenc, Spawalnictwo. Warszawa, *WNT*, 2009. 262 s.
[25] Brodziński A., Laboratorium ogólne - maszyny i urządzenia do obróbki plastycznej. Lublin, Poland, *Wydaw. Uczelniane PL*, 1993. 156 s.
[26] Kennametal Stellite.Kennametal Stellite https://www.stellite.com/us/en/home.html.
[27] OK Tigrod 308LSi - pręt spawalniczy.www.rywal.com.pl.
[28] Klimpel A., Podręcznik spawalnictwa: Technologie spawania i cięcia.*Wydawnictwo Politechniki Śląskiej*, 2013. 764 s.
[29] Pilarczyk J., Poradnik inżyniera: spawalnictwo (in Polish)/ Engineering handbook: welding. Poland, *Wydawnictwa Naukowo-Techniczne*, 2008. 1068 s.
[30] Zhu Z., Ouyang C., Qiao Y., Zhou X., Wear Characteristic of Stellite 6 Alloy Hardfacing Layer by Plasma Arc Surfacing Processes.T. 2017, Scanning. *Hindawi*, 2017. s. e6097486. https://doi.org/10.1155/2017/6097486
[31] Gomes R., Henke S., D´Oliveira A.S., Microstructural control of Co-based PTA coatings. *Materials Research* , 2012, Vol. 15(5), 796–800.