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Laser Overlay Welding of Graded Layers

Abstract: Graded materials are increasingly commonly used as structural materials in many advanced engineering structures. These materials are usually characterised by the gradual change of a specific functional parameter, usually in the direction of thickness. The article presents the general characteristics of graded metals and their manufacturing methods. On the basis of selected results of author's own research it was possible to determine the possibility of making graded layers using powder-based laser overlay welding.

Keywords: laser welding, overlay welding, graded layers, powder-based laser

Introduction

In many cases the functional properties of various elements of mechanical structures depend mainly on their surface layer properties determining the operational efficiency and structural reliability or on the properties of individual components, frequently exposed to material ultimate strength conditions and operated in very aggressive environments. Excellent structural materials should be at the same time characterised by high core ductility and possibly highest operating wear resistance. Such parameters are provided by various wear-resistant coatings usually applied using various welding methods which, while changing surface properties, simultaneously protect the material core responsible for load transfer. Applying a specific kind of material is usually connected with the creation of the strong gradient of properties in the intermediate zone, usually becoming the source of various imperfections such as cracks, laminar imperfections or a rapidly changed specific material functional parameter.

In many technological cases it is required that the change of material properties should be gradual, smooth and controlled in a specific direction ensuring the best possible adjustment of a specific structural element for expected operating conditions. Such properties characterised so-called functionally graded materials (FGM –Functionally Graded Materials).

General Characteristics of Functionally Graded Materials and of their Production Method

The properties of various structural materials as well as their advantages and disadvantages result from the limitations of individual technologies used in order to produce such materials. For instance, in the case of metal alloys the restrictions are imposed by the limited mutual solubility of alloying components or significantly different melting points of individual components. In powder metallurgy the production of structural elements can be limited, for instance, by the shape of an element to be

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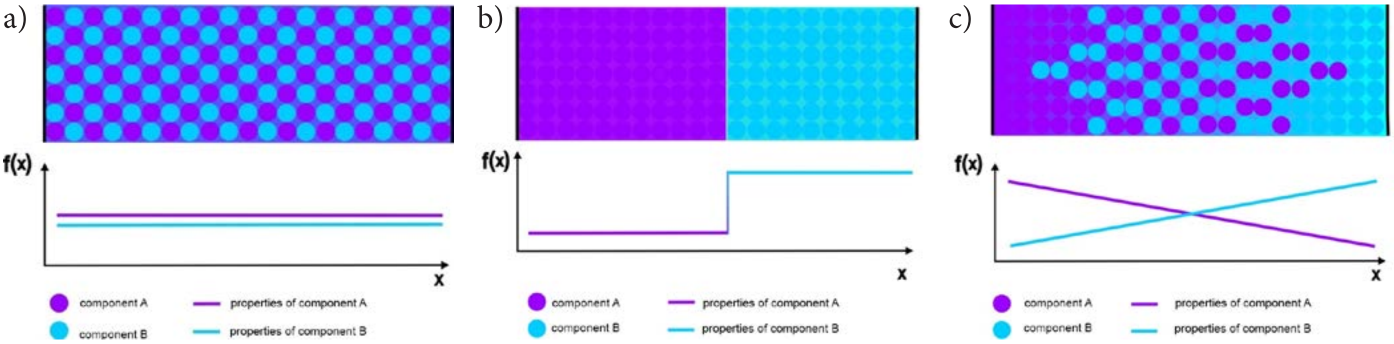


Fig. 1. Properties of: homogenous (a), composite (b) and graded (c) materials

made, porosity or low strength. However, advanced structural materials, such as composites, characterised by high strength and, at the same time, low weight, tend to delaminate at very high temperatures (e.g. various types of thermal barriers) due to the very high gradient of properties characterising individual components.

Functionally graded materials do not have a zone characterised by the strong gradient of properties, i.e. sensitive to various imperfections (e.g. intermediate areas between individual material components). Such a zone is replaced by an area of gradually changing properties, which enables the best possible adjustment of a given material for expected functions and applications (Fig. 1).

The gradual change of material properties is due to the "smooth" change of the volume fraction of components in the intermediate zone. Component A initially playing the role of matrix for component B changes its function and becomes a component "deposited" in the matrix formed by component B (Fig. 1c).

The gradual change of functional or structural properties may take place in various directions. Mostly, this change takes place along the material thickness (Z-axis) (Fig. 2).

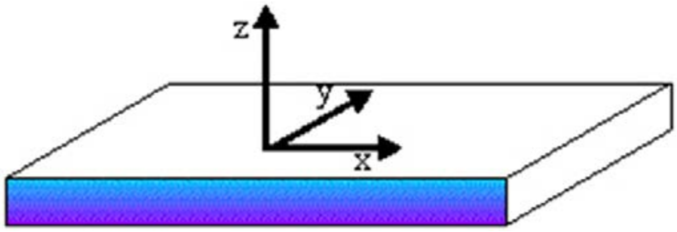


Fig. 2. Possible direction of material property change

These changes can be gradually stepless or stepped, in the whole material volume or in specific zones, usually in the coating or the intermediate zone (interface) between various components (Fig. 3).

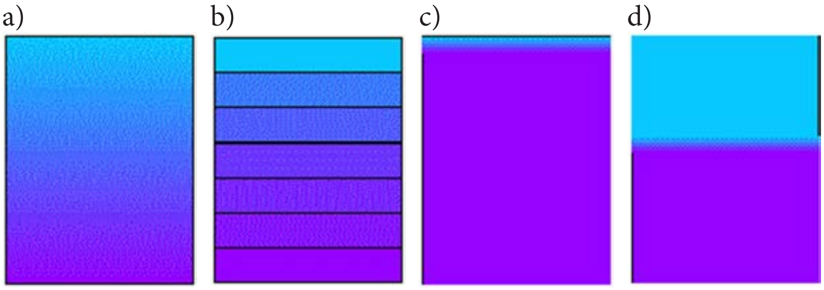


Fig. 3. Scheme of property change in the graded material volume: a) stepless b) stepped, c) in the coating d) in the intermediate zone

The stepless (smooth) property change can be obtained, e.g. as a result of the continuous change of the fraction of individual material components along the material thickness. Stepped changes are obtained by appropriately selected various materials arranged in layers along the material thickness. In relation to the

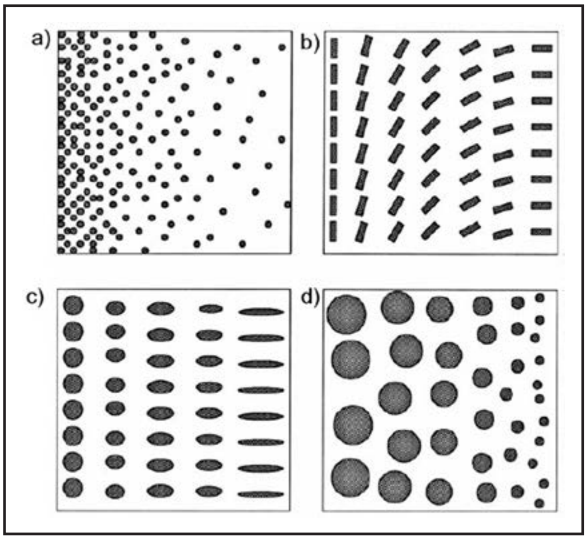


Fig. 4. Gradient of volume fraction (a), orientation (b), shape (c) and size (d) of component [1]

microstructure, the gradient can refer to the volume fraction, orientation, shape and size of a component (Fig. 4).

Graded materials are usually present in the form of thin layers or large volume spatial elements. Small thickness graded layers are made using the physical (PVD) or chemical (CVD) vapour deposition of metals or non-metals on a specific substrate. Vapour deposition methods enable the obtainment of graded layers characterised by excellent microstructure, yet they can be used only for very thin layers. These methods are very time-consuming and generate by-products in the form of toxic gases. Other methods include, e.g. ion beam assisted deposition (IBAD) electrodeposition, electrophoretic deposition or self–propagation high-temperature synthesis (SHS).

The methods enumerated above are usually low-efficient and energy-consuming. They enable making layers of very small thicknesses (in micrometres). For this reason, these methods cannot be used in fabricating large volume functionally graded materials, i.e. the most useful in the production of specific structural materials. In practice, such elements are made using powder metallurgy or centrifugal casting.

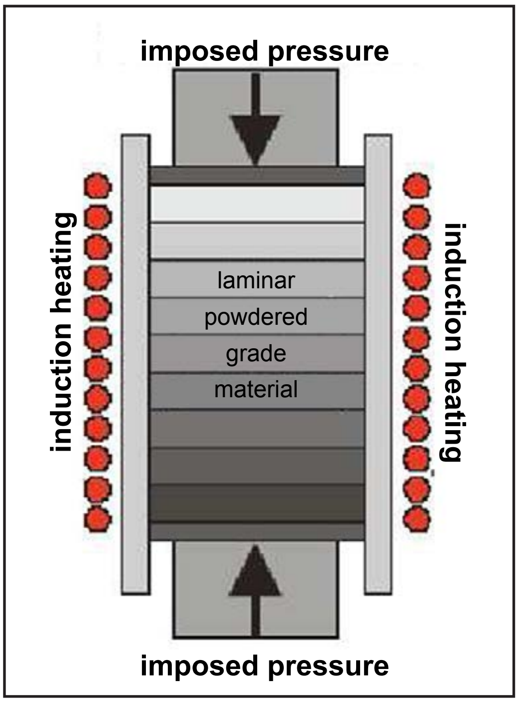


Fig. 5. Making graded materials of stepped property change of charge material in the form of powder [2]

The metallurgy of powders enables making structural elements of functionally graded materials characterised by significantly large volume and stepped change of properties along one of directions – usually the thickness (Fig. 5). The fabrication process includes several stages:

- preparing a powder composition of specific ingredient fractions, in accordance with anticipated spatial arrangement of individual mixtures in the volume of an element to be made and dictated by its functionality,
- depositing layers of initially prepared mixtures,
- mixture consolidation and sintering.

Materials characterised by continuous property change are usually made using the centrifugal casting method taking advantage of various densities of components and centrifugal force generated in a mould set in rotary motion (Fig. 6). This, to some extent, limits the gradient of material properties (combinations of materials having specific density and adjustment of centrifugal force) as well as the shape of a finished product (usually elements of rotational symmetry).

Figure 6 presents the scheme of centrifugal casting in a form used for making graded materials based on nanopowders [3]. At the first stage the mixture of metal matrix A powder and of component B nanoparticles is placed in a rotating mould (Fig. 6a). Afterwards, the matrix metal block undergoes melting in a melting pot and is poured into a rotating mould containing the mixture of powders A+B (Fig. 6b). As a result, the matrix molten metal penetrates the space between powder mixture grains due to pressure triggered by the centrifugal force of the rotating mould (Fig. 6c) simultaneously melting the grains of matrix A metal powder (Fig. 6d). The final stage of the process is connected with the obtainment of a graded material ring with component B fraction gradually increasing in the direction of the outer surface (Fig. 6e).

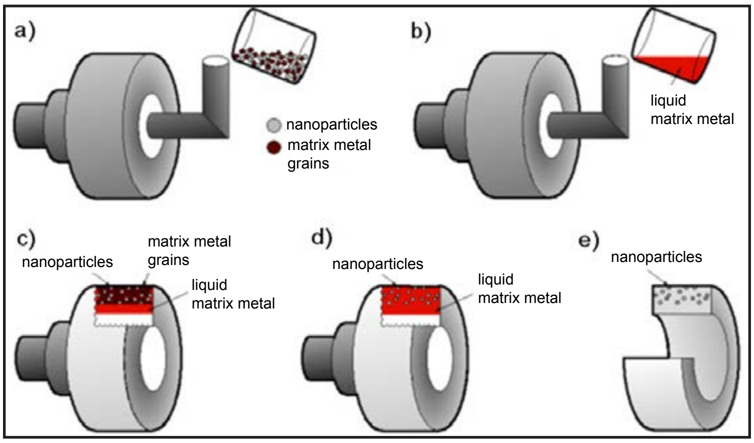


Fig. 6. Making of graded materials characterised by continuous property change [3]

Graded Layers Made using Powder Laser Overlay Welding

Presently, the search for technologies enabling the production of new graded material compositions is focused not on the whole form of a material (e.g. due to difficulty obtaining elements of specific shapes) but rather on the obtainment of surface graded layers on ready-made structural materials. The method most commonly used for making such layers is laser overlay welding, particularly overlay welding utilising multicomponent powders.

The tribological properties of the weld depend on the proportion of the volume fraction of the matrix and of the hard phase components as well as on the structure homogeneity degree.

In an overlay weld made of homogenous (one-component) powders, the hard phase (carbides) is formed due to physico-chemical reactions taking place during overlay welding. The fraction of the hard phase affecting the hardness of a layer subjected to overlay welding results from the amount and types of alloying components in the powder.

A hard phase fraction increase in an overlay weld can be obtained by overlay welding with two powders (multi-component powders). The components of one of the powders form a plastic metallic matrix in which grains of significant hardness coming from the other powder (in the form of compounds such as WC, SiC, TiC, having features of a ceramic material) are deposited. The hard phase of this kind of powders is formed not only as a result of physico-chemical reactions during overlay welding but is the initial component of multi-component powders. Tungsten carbide is often used as the hard phase component. In comparison with other carbides such as SiC and TiC, tungsten carbide combines advantageous properties such as high hardness, high density and good wettability by a molten metal [4].

Overlay welding using multi-component powders enables the obtainment of overlay welded layers having complex chemical composition and properties. This method is increasingly frequently used in making complex composite (e.g. metal-carbide) coatings. The traditional techniques used for this purpose such as thermal spraying, plasma spraying or arc overlay welding have specific advantages and disadvantages. Thermal spraying is very efficient but does not ensure good joint between the surface layer and the substrate. In turn, arc-based technologies, less efficient if compared to thermal spraying, provide significant heat input to a material subjected to overlay welding, leading to significant fusion into the substrate and significantly greater stirring of the overlay weld material with the substrate. Laser overlay welding appears to be the most convenient technology combining the advantages of both methods as it ensures slight stirring and, at the same time, good joining of the overlay weld with the substrate. In addition, the hard phase particles (carbides) do not undergo excessive dissolution, providing appropriate mechanical properties of the surface layer.

Laser overlay welding using multi-component powders provides the effective supply of hard phase particles (e.g. SiC, TiC and WC carbides) to the metal matrix being mainly composed of such alloying components as Ni, Co or Fe thus leading to the formation of ceramic-metal overlay welds characterised by significant hardness and abrasion resistance. However, making such overlay welds faces numerous challenges and for this reason has not been widely used in industry, being limited mainly to special applications.

The basic limitations include overlay welded layer cracking and low process efficiency. Crack formation in an overlay welded coating is a complex phenomenon affected not only by the thermo-physical properties of the substrate and those of the overlay weld material, such as melting point, coefficient of elasticity or thermal expansion coefficient, but also by process conditions including process parameters, metallic matrix composition, carbide fraction in the powder mixture and the sizes of grains in individual powder fractions [5]. There are various techniques used for lowering overlay weld cracking susceptibility adjusted to the requirements of a specific technological task. These include the optimisation of process parameters, the use of radiation beam emitted in the pulsed mode, additions of rare-earth elements or of metal oxides to the powder, preheating or the use of graded layers. These techniques can be used jointly or separately [5]. Conventional one-layer overlay welds made of powder having specific fractions of the hard phase and of the matrix can reveal inadequate adhesion or excessively high stresses between the surface layer and the substrate, which leads to cracking, peeling or chipping of these layers. Cracks are connected with the hard phase fraction in the powder for overlay welding and the strong gradient of physical properties arising thereof (particularly in the intermediate zone between the substrate and the overlay weld). It is in this zone that cracks are usually initiated [6].

The reduction of the disadvantageous effect of the intermediate zone and the moderation of the gradient of physical properties can be obtained in various manners. A very slight moderation of the gradient of property changes can take place if not one, but several layers (of smaller thicknesses) are applied using a powder having the same fractions of individual components of the matrix and of the hard phase (Fig. 7).

The change of overlay weld properties is then obtained by a slight change in the fraction of the substrate material and of the hard phase in the individual layers caused by specific degree of stirring with the previous layer.

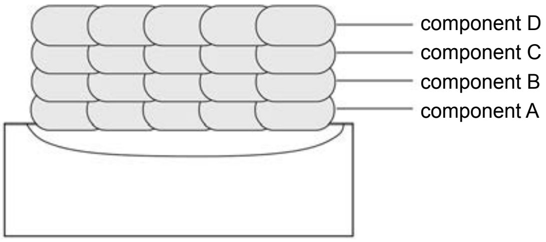


Fig. 7. Conventional multilayer overlay weld; each layer is made using powder having the same fractions of individual components of the matrix and of the hard phase

The stronger moderation of the gradient of property changes in the intermediate zone can be obtained by making successive overlay weld layers of filler metals of appropriately selected different chemical compositions (wire or powder – Fig. 8a) or of the same chemical composition but with various fractions of individual components (multi-component powders) in each successively applied layer (Fig. 8b).

The graded layers obtained in this way change their properties in a stepped manner

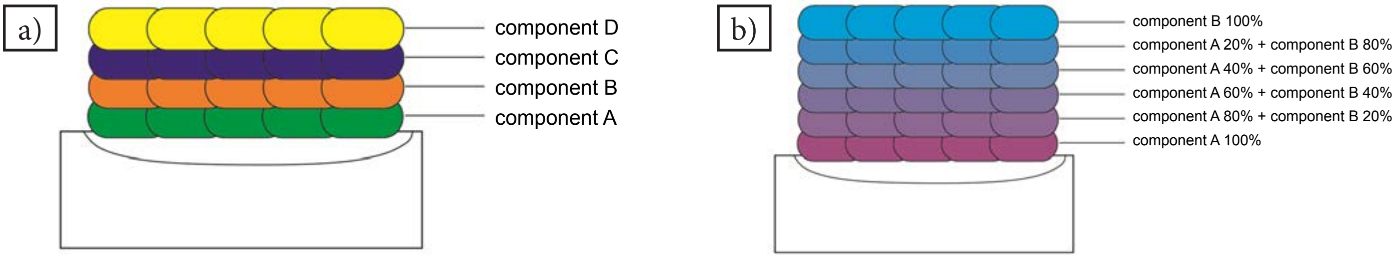


Fig. 8. Examples of laser welded graded layers
a) layer of stepped change of properties, b) layer of quasi-steady change of properties

(Fig. 8a) or steadily (Fig. 8b), enabling the limitation or elimination of the imperfections referred to above. The process of powder-based laser overlay welding of typical graded layers of quasi-steady change of properties (Fig. 8b) consists in providing powder to each successively applied layer located in the laser radiation affected area; the powder is a mixture of two components of appropriately selected fraction of hard carbide particles and ductile metallic matrix. Due to very fast crystallisation of the molten metal pool the carbide grains (unmelted or partly melted) become deposited in the plastic matrix.

Overlay welded graded layers tend to reveal higher hardness and wear resistance than layers applied in a conventional manner and significantly increase the life of machinery parts exposed to complex loads such as abrasion, impact or thermal and mechanical fatigue [7].

The individual layers can play various roles. The first layer (made up of the powder without the hard phase fraction) usually constitutes a buffer layer which joins well both with the substrate material and with successive layers of appropriately selected properties. The powder used for making successive layers is selected by changing the fractions of individual phases (matrix and hard phase) in a manner enabling the obtainment of increased resistance of overlay welded material surface layer to a specific type of wear in predefined operating conditions. Usually the surface layer is characterised by higher hardness than that of the basic layer.

The process of powder-based laser overlay welding of graded layers can involve various combinations of overlay weld components and the adjustment of an overlay weld to the substrate material (as is the case with conventional laser overlay welding).

Technological Tests and Tests of Powder-based Laser Overlay Welding of Graded Layers

The technological tests of powder-based laser overlay welding of graded layers were conducted using a robotic station equipped with a Kuka KR30HA industrial robot, a TruDisk 12002 YAG disc laser (12 kW) manufactured by Trumpf and a specialist head for overlay welding (Fig. 9). The head is provided with a focusing lens having a focal length of 220 mm. The laser radiation beam was supplied to this head using a standard optical fibre having a diameter of 600 µm. The electric control of the head collimator lens position enables the automatic change of laser beam focus position within the -4.3 mm ÷ +481 mm range, thus enabling changes of the laser radiation focusing area size.

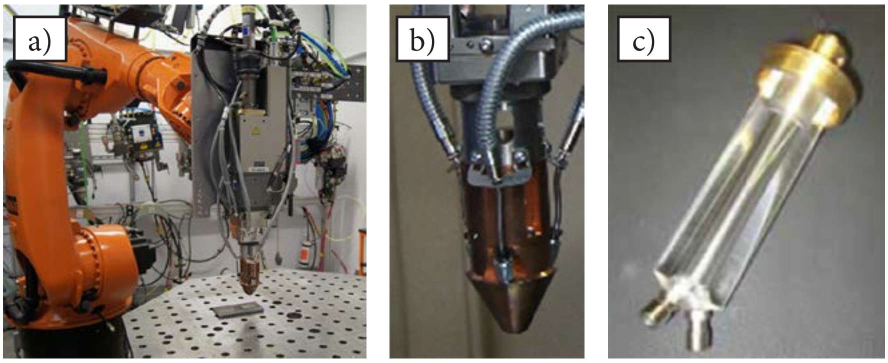


Fig. 9. Head for overlay welding installed on the robotic laser station (a), an ND16 three-way process nozzle (b), powder distributor (c)

The overlay welding head was provided with an ND16 three-way process nozzle (Fig. 9b) for creating the centre of powder streams coaxially in relation to the laser radiation beam. The powder for overlay welding is provided to the process nozzle via the acrylic powder distributor which (directly before the nozzle) homogenizes the powder stream and divides it into three single streams directed to three ducts uniformly arranged around the nozzle circumference. Three powder streams are directed at a specific angle in relation to the nozzle axis and become concentrated 16 mm away from the nozzle face (Fig. 10).

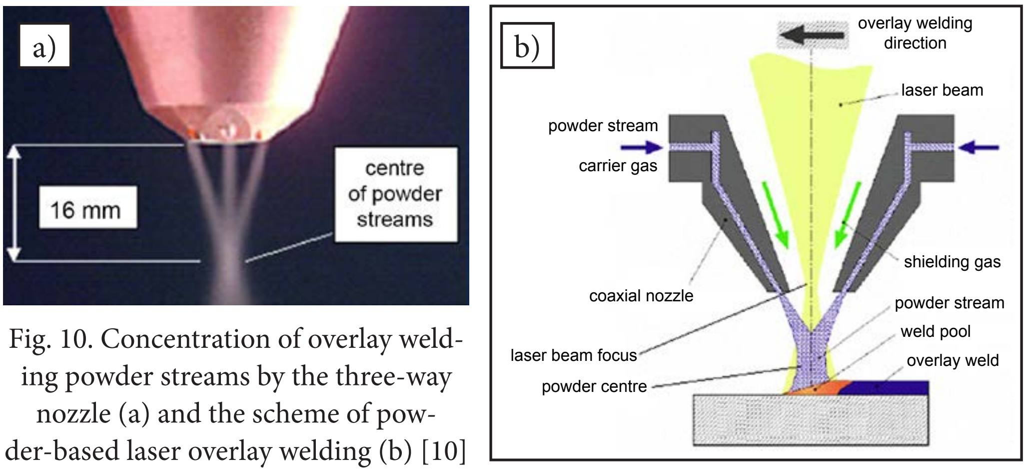


Fig. 10. Concentration of overlay welding powder streams by the three-way nozzle (a) and the scheme of powder-based laser overlay welding (b) [10]

The laser radiation power for the nozzle should exceed 4000 W. The nozzle can be set at an angle of ±90° in relation to the surface subjected to overlay welding, thus enabling overlay welding of spatial elements. The powder for overlay welding is supplied to the nozzle from the feeder equipped with two programmable powder containers independent from each other. This enables preparing a powder mixture composed of two different materials. Each powder container is integrated with a feeding module, in which the powder undergoes homogenisation and is mixed with a carrier gas (helium). A rotating disc (feeding board) in the feeding module moves the powder poured from the container to the powder connector from which, in turn, the powder is sucked and directed to the transport duct and next moved to the process head of an appropriate laser device.

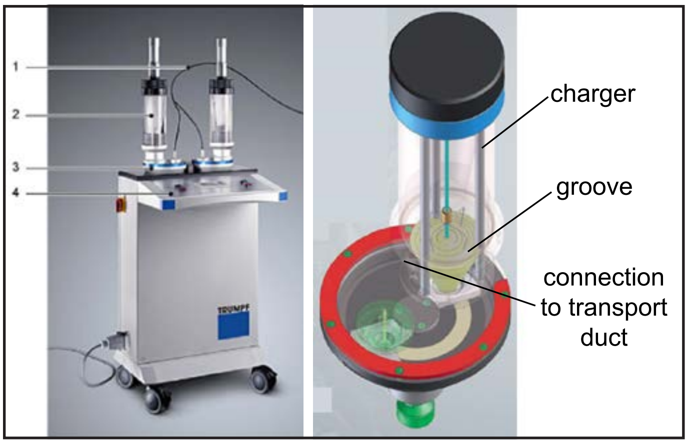


Fig. 11. Powder feeder (a) powder container integrated with the feeding module (b) [11]; 1) powder transport duct, 2) feeding module , 3) feeding disc (board) module, 4) control panel

The amount of powder is permanently controlled by adjusting the carrier gas flow rate and the rotation rate related to the disc moving the powder from the container to the transport duct (Fig. 11). On the basis of previous experience of the author [8] the laser radiation beam focus was located 25 mm away from the powder centring plane, as a result of which it was possible to obtain the laser beam focusing area having a diameter of approximately 3 mm. The overlay welding rate adopted was that of 1 m/min, which corresponds to the average laser overlay welding rate. It was also assumed that the overlay weld width – overlay weld height ratio should be that of 3:1. The laser radiation beam power amounted to 2500 W. The amount of powder fed was determined on the basis of filling the cross-section of an overlay weld of an assumed shape (width 3 mm, height 1 mm) and the obtainment of a proper single-run overlay weld characterised by a possibly low degree of stirring with the substrate material, adopting the basic overlay welding process parameters specified above.

The basic process parameters specified above were used in all the overlay welding technological tests. Multi-run single- and multilayer overlay welds 45 mm in length and 22 mm in width were made on the substrate of S355 unalloyed steel and on steel characterised by a high carbon equivalent value (55NiCrMoV7, 41Cr4). The overlay weld was composed of nickel-based (Inconel 625) or cobalt-based (Stellit 6) powders having various hard phase volume fractions (spherical tungsten carbide). The powders used had the same granulation of 45÷90 µm.

The different amount of carbides in the individual layers enabled the obtainment of graded overlay welds having variable properties (particularly hardness) along their thickness.

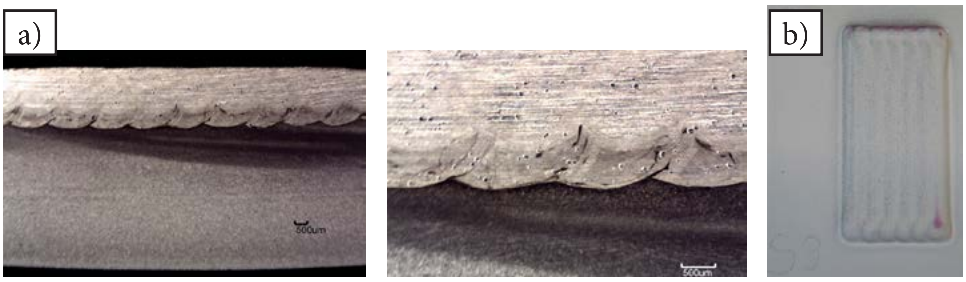
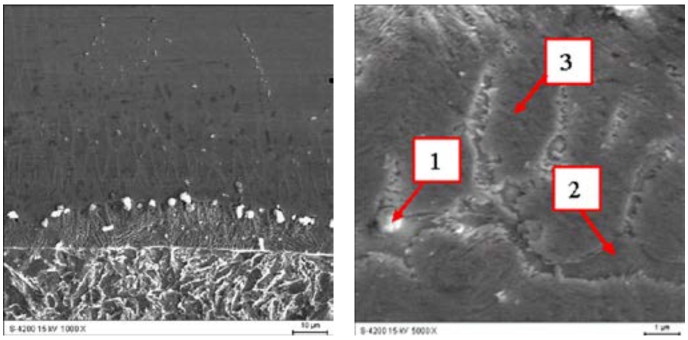
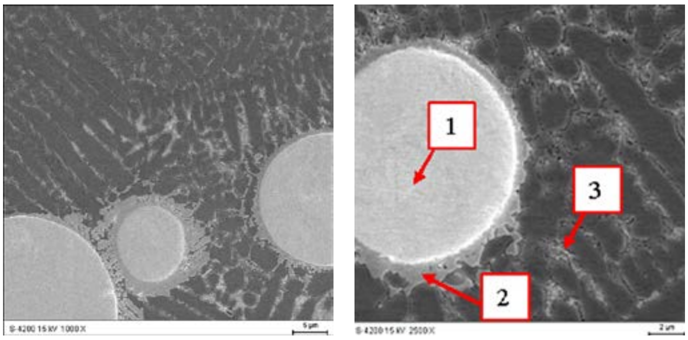


Fig. 12. Macrostructures in the cross-section of the multi-run two-layer overlay weld and (a) the overlay weld after PT (b): substrate - S355 steel, overlay weld – Stellit 6+WC (95%-5%)



% by weight	Cr	Mn	Fe	Co	W
S9-swc_p1	7,97	2,21	66,79	13,60	6,24
S9-swc_p2	9,80	1,51	66,38	16,60	5,71
S9-swc_p3	5,18	1,39	76,04	14,23	3,16

Fig. 13. Microstructure of the fusion area and HAZ of the multi-run two-layer overlay weld: substrate - S355 steel, overlay weld – Stellit 6+WC (95%-5%)



% by weight	Cr	Fe	Co	W
S9-swc_p1				100,00
S9-swc_p2	14,81		20,92	64,28
S9-swc_p3	30,70	3,69	38,38	27,18

Fig. 14. Microstructures of the multi-run two-layer overlay weld: substrate - S355 steel, overlay weld – Stellit 6+WC (95%-5%)

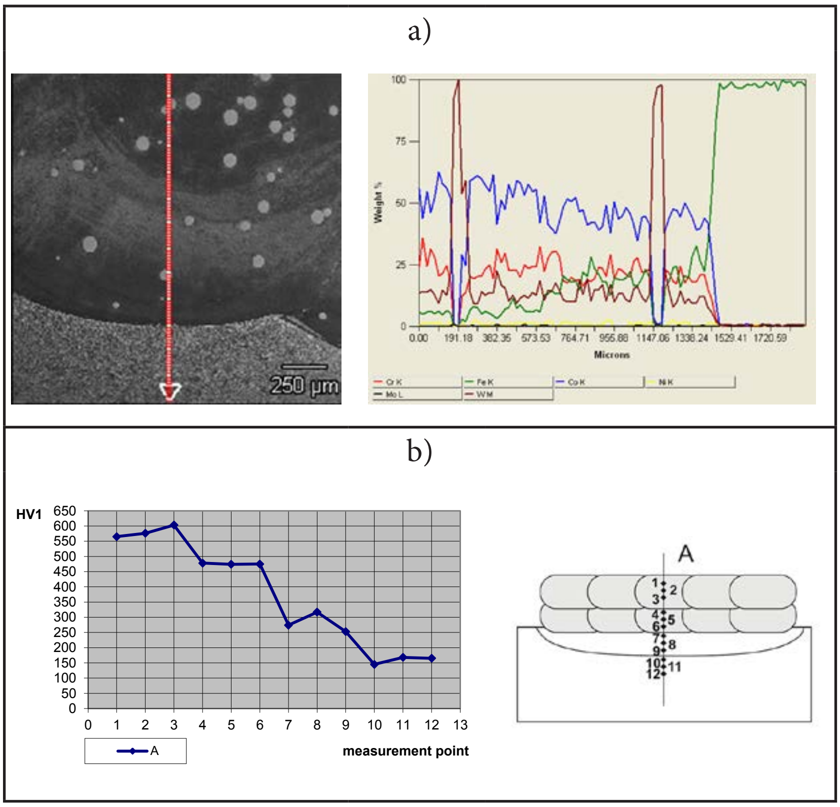


Fig. 15. Linear distribution of alloying element contents and hardness distribution in the multi-run two-layer overlay weld: substrate - S355 steel, overlay weld – Stellit 6+WC (95%-5%)

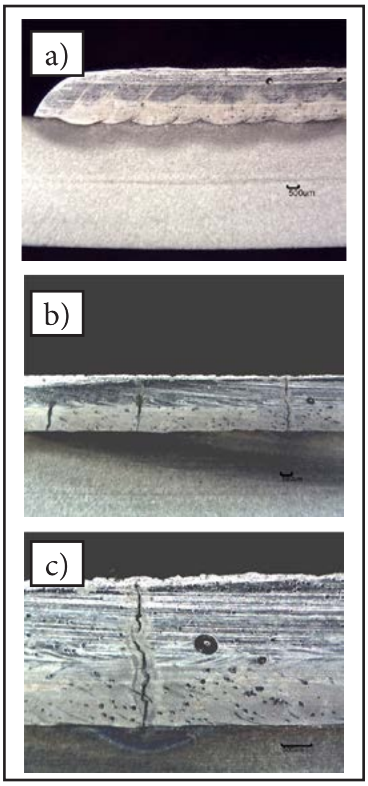


Fig. 16. Macrostructure in the cross-section (a) and longitudinal section of (b) the multi-run two-layer overlay weld: substrate - S355 steel, overlay weld – Stellit 6+WC (95%-5%, 90%-10%)

However, the changes were not significant and resulted from the limited carbide fraction not causing cracks in the overlay weld. In turn, the limited carbide fraction resulted from the fact that the element subjected to overlay welding had not been subjected to preheating (assumption adopted in the tests).

The adopted overlay welding process conditions (equipment, adopted process parameters, overlay welded element not subjected to preheating) enabled the obtainment of proper overlay welds with the hard phase (tungsten carbide) fraction in the overlay welding powder restricted within the 5÷25% range depending on the heat capacity of the element subjected to overlay welding and on the manner of applying the successive overlay weld layers (constant hard phase fraction, variable hard phase fraction, buffer layers without hard phase fraction), Fig. 12÷24 [9].

The use of Stellit 6 alloy as the matrix of tungsten carbide grains made it possible to provide the overlay welding powder mixture with approximately 5÷7% of tungsten carbide and to obtain proper (crack-free) overlay welds without preheating the substrate material. The structural tests of the two-layer overlay weld (Fig. 12) (the overlay weld is composed of Stellit 6 -95% and WC -5%) revealed that the fusion area contained a zone of crystals accumulating perpendicularly to the substrate (Fig. 13). On the boundaries of such crystals it was possible to observe phases rich in iron (66%), cobalt (17%) and chromium (10%), whereas in the areas of the crystals it was possible to observe a greater content of Fe (76%) and smaller contents of chromium (5%) and cobalt (14%) (Fig. 13). These results indicate the significant stirring of the overlay weld material with the substrate material in the first layer (approximately 15% - Fig. 15a).

The overlay weld contained spherical precipitates rich tungsten and eutectic areas (also rich in tungsten) surrounding the precipitates (Fig. 14, item 1 and 2 and Fig. 15a). The results indicate that the precipitates are tungsten carbides. The interdendritic areas contained eutectics rich in cobalt, chromium, tungsten and iron – approximately 4% (Fig. 14, item 3). Attempts to provide a greater amount of carbide to the Stellit matrix initiated transverse crack formation in the overlay weld (Fig. 16).

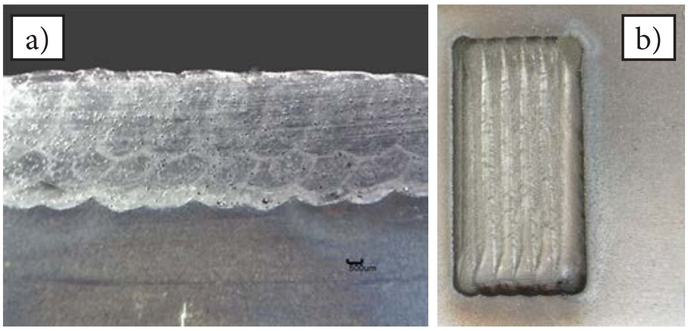


Fig. 17. Macrostructure in the cross-section of the multi-run three-layer overlay weld (a) and the main view of the overlay weld (b); substrate - S355 steel, overlay weld – Inconel 625+WC (87%-13%)

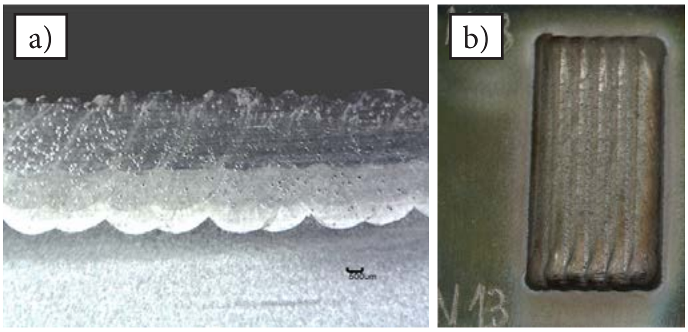
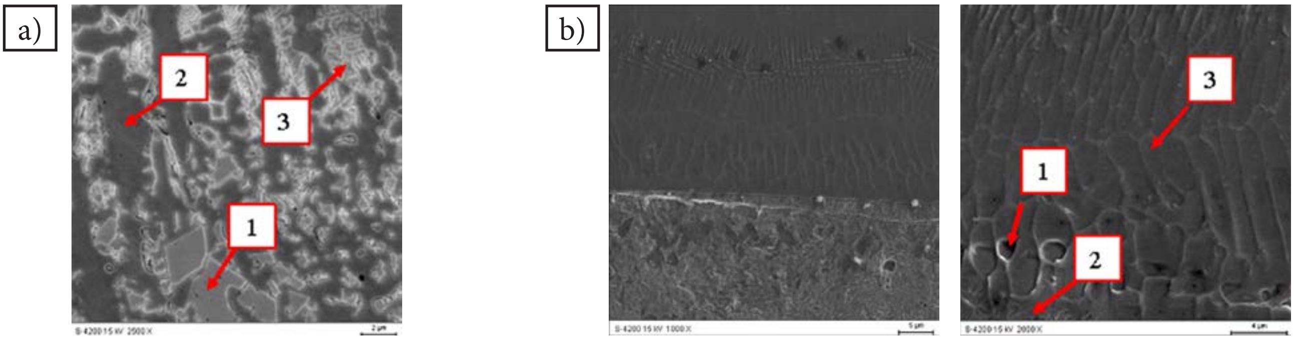


Fig. 18. Macrostructure in the cross-section of the multi-run three-layer overlay weld (a) and the main view of the overlay weld (b); substrate - S355 steel, overlay weld – Inconel 625+WC (95%-5%, 90%-10%, 85%-15%)

Nickel alloys offer a more convenient matrix for spherical tungsten carbides. In this case it was possible to use a greater carbide fraction in the powder mixture. In case of the unchanged fraction of carbide in the crack-free single or multilayer overlay weld this fraction can reach approximately 10% (Fig. 17). A greater fraction of spherical tungsten carbide in the powder mixture for overlay welding can be used in the overlay welding of graded layers. Figure 18 presents a multilayer overly weld in which the last layer was made with the 15% carbide fraction; the overlay weld was crack-free and did not require substrate preheating. In the three-layer overlay weld on the nickel matrix it was possible to observe (similarly as in other cases) structures typical of fast crystallisation, i.e. crystals arranged perpendicularly to the heat offtake direction (Fig. 19b, item 3). The interdendritic areas contained eutectic rich in nickel, chromium, iron, molybdenum and wolfram (Fig. 19a, item 3). The overlay weld structure also contained precipitates of polygonal phases rich in tungsten (Fig. 19a, item 1). The examination of the fusions zones of individual layers did not reveal any significant chemical composition heterogeneity. In the whole overlay weld it was possible to observe numerous globular phases rich in tungsten (Fig. 20a).

Good results can be obtained by using buffer layers not containing the hard phase in the form of carbides (Fig. 21). While making similar welds with the buffer layer on the substrate made of 55NiCrMoV7 tool steel (Inconel 625 and WC of the fraction 100%-0% and 80%-20% respectively) it was possible to obtain a hard phase content in the surface layer similar to that in the graded layer, without overlay weld crack and crack initiated in HAZ, in spite of high hardness characterising this zone (Fig. 21, 24). The line of fusion into the substrate material was covered by a film enriched in iron (approximately 89%) (Fig. 22, item 2), having a width of approximately 10 μm (Fig. 22). The increase in the distance from the parent metal is accompanied by a rapid increase in a nickel content and a decrease in an iron content (Fig. 22, item 3). The overlay weld contained a dendritic structure of columnar crystal arrangement (Fig. 23). The interdendritic areas were characterised by increased molybdenum and chromium contents (Fig. 23, item 2), whereas crystals were predominantly characterised



overlay weld mag. 2500x

fusion line mag. 1000x

HAZ mag. 2000x

% by weight	Cr	Fe	Ni	Mo	W
N13-nap_p1	10,62	3,66	19,92	12,14	53,66
N13-nap_p2	16,59	11,00	55,96	3,91	12,54
N13-nap_p3	16,09	8,48	45,76	7,15	22,52

% by weight	Cr	Mn	Fe	Ni	Mo	W
N13-swc_p1	3,79	1,26	81,30	11,41		2,23
N13-swc_p2	3,57	1,47	82,92	9,15	0,86	2,02
N13-swc_p3	7,73	1,09	60,78	23,62	2,64	4,14

Fig. 19. Microstructure of the overlay weld (a) and fusion area and HAZ (b) of the multi-run three-layer overlay weld and chemical composition analysis results for selected areas: substrate - S355 steel, overlay weld – Inconel 625+WC (95%-5%, 90%-10%, 85%-15%)

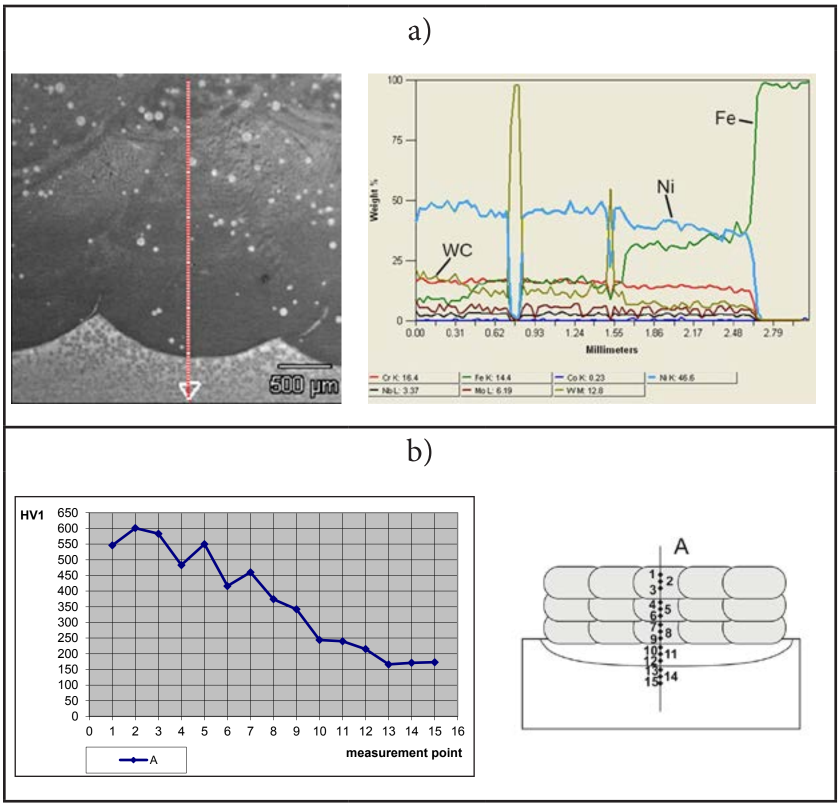


Fig. 20. Linear distribution of alloying element contents and hardness distribution in the multi-run three-layer overlay weld: substrate - S355 steel, overlay weld – Inconel 625+WC (95%-5%, 90%-10%, 85%-15%)

by an increase in nickel content (Fig. 23, item 3). The overlay welds also contained globular precipitates rich in tungsten (Fig. 23, item 1) (probably tungsten carbides). The analysis of chemical element distribution on the first layer fusion line indicates a significantly high degree of stirring with the substrate material (Fig. 24).

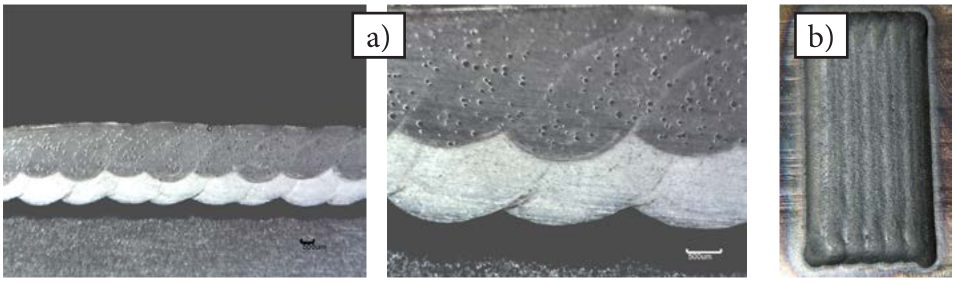
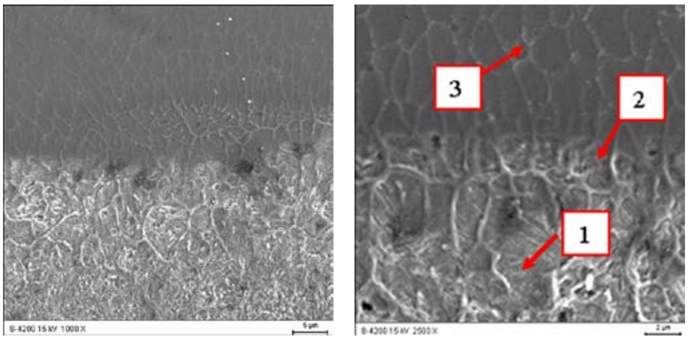


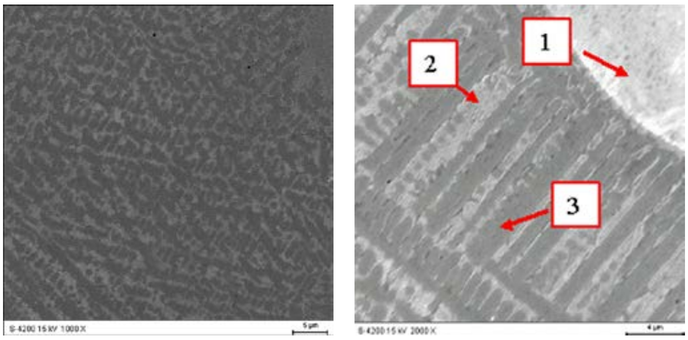
Fig. 21. Macrostructures in the cross-section of the multi-run two-layer overlay weld (a) and the main view of the overlay weld (b): substrate - 55NiCrMoV7 steel, overlay weld – Inconel 625+WC (100%-0%, 80%-20%)



fusion line mag. 1000x HAZ mag. 2500x

% by weight	Si	Cr	Fe	Ni	Mo
WNL7-swc_p1	0,90	4,80	93,12		1,18
WNL7-swc_p2	0,88	5,56	88,63	3,70	1,23
WNL7-swc_p3	0,88	11,55	60,85	23,71	3,01

Fig. 22. Microstructure of the fusion area and HAZ of the multi-run two-layer overlay weld and chemical composition analysis results for selected areas: substrate - 55NiCrMoV7 steel, overlay weld – Inconel 625+WC (100% -0%, 80%-20%)



overlay weld mag. 1000x overlay weld mag. 2000x

% by weight	Cr	Fe	Ni	Nb	Mo	W
WNL7-nap_p1						100,00
WNL7-nap_p2	16,15	13,85	37,51	3,62	8,71	20,16
WNL7-nap_p3	15,52	19,08	49,21		4,17	12,02

Fig. 23. Microstructures of the multi-run two-layer overlay weld and chemical composition analysis results for selected areas; substrate - 55NiCrMoV7 steel, overlay weld – Inconel 625+WC (100%-0%, 80%-20%)

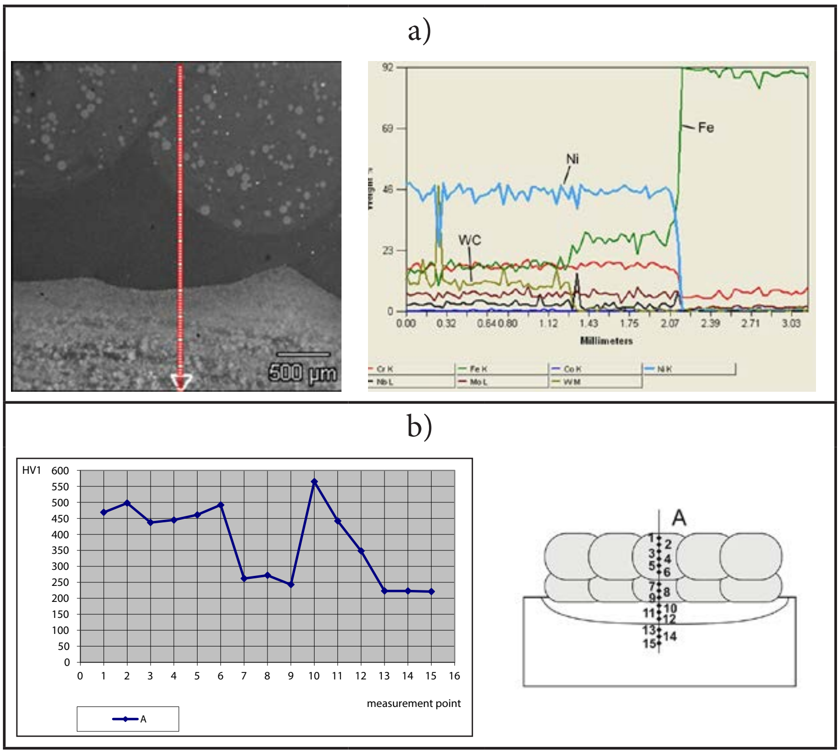


Fig. 24. Linear distribution of alloying element contents and hardness distribution in the multi-run two-layer overlay weld: substrate - 55NiCrMoV7 steel, overlay weld – Inconel 625+WC (100%-0%, 80%-20%)

Summary

Proper multi-layer overlay welds with constant or variable (graded overlay welds) fractions of components in the powder mixture for overlay welding in individual layers, made using Stellit 6 and Inconel 625 overlay welding powders with an appropriate tungsten carbide content, without preheating the substrate material and following other conditions adopted in the work are characterised by a relatively low hard phase fraction and, on average, between ten and twenty percent degree of stirring with the substrate material in the first layer.

The significant hard phase fraction in the surface layer of the overlay weld was obtained to a comparable degree using a specific hard phase gradation in individual layers, the first of which is applied directly on the substrate subjected to overlay welding or by applying appropriate buffer layers (type and number), not containing hard phase grains, directly on the substrate subjected to overlay welding and successive layers of a significant hard phase fraction. The obtainment of proper graded overlay welds is significantly affected by the selection of a material constituting matrix for hard phase grains. The use of nickel alloys meets this objective.

The technological tests confirmed the possibility of powder-based laser overlay welding of steel having a high carbon equivalent (55NiCrMoV7 and 41Cr4 steels) without preheating and obtaining proper overlay welds free from cracks in the surface layer. The powder-based laser overlay welding method is particularly useful for overlay welding small fragments of large elements. In comparison with arc-based method, powder-based laser overlay welding makes it possible to significantly reduce heat input to an element subjected to overly welding (minimisation of deformations), limit the overlay welded material wear and reduce overlay weld processing costs (smaller allowances).

Laser overlay welding of graded layers can appear useful particularly in so-called incremental production as regards rapid prototyping, rapid manufacturing or rapid tooling. This method enables making uniform spatial elements of practically any shape characterised by various properties in individual sections.

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