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Foresight methods application for evaluating laser treatment of hot-work steels

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Abstract

Purpose: *The purpose of this chapter is to evaluate the strategic growth perspectives of laser treatment of X40CrMoV5-1 and 32CrMoV12-28 hot-work alloy tool steels using NbC, TaC, TiC, VC and WC carbide powders. The criterion assumed for dividing the technologies into groups was the powder type; thus, five groups were selected to realised research.*

Design/methodology/approach: *As a part of the foresight-materials science research, a dendrological matrix of technology value, a meteorological matrix of environment influence, and a matrix of strategies for technologies were elaborated, the strategic development tracks were determined, and materials science experiments were conducted using a scanning electron microscope, an optical microscope, a transmission electron microscope, a microhardness tester, a scratch tester, an X-ray diffractometer, an electron microprobe X-ray analyzer and a device for testing of heat fatigue and abrasive resistance. Also, technology roadmaps were prepared.*

Findings: *The research conducted demonstrated huge potential and attractiveness of the analysed technologies, compared to others, and the promising properties improvement of the tested surface layers, as a result of laser surface treatment.*

Research limitations/implications: *Research concerning laser treatment of hot-work alloy tool steels constitute a part of a larger research project aimed at identifying, researching, and characterizing the priority innovative technologies in the field of materials surface engineering.*

Practical implications *The presented results of experimental materials science research prove the significant positive impact of laser treatment on the structure and the properties of hot-work alloy tool steels, which justifies including them in the set of priority innovative technologies recommended for use in small and medium enterprises and in other business entities.*

Originality/value: *The value of this chapter lies in the fact that it determines the value of laser treatment of hot-work alloy tool steels compared to other technologies and identifies the recommended strategic development tracks and technology roadmaps for them, taking into account the impact of such treatment on hardness, abrasion resistance, and coarseness of the tested surface layers.*

Keywords: *Manufacturing and Processing; Laser Surface Treatment; Hot-work steels; Foresight; Technology Roadmapping*

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1. Introduction

The increasing role of advanced technologies in our daily lives is one of the key trends that determine the way the contemporary world works. The Internet is more and more often used to perform various processes that require exchange of information, goods or capital, which makes these processes simpler, more efficient, and faster. Terms such as e-management, e-business, e-commerce, e-banking, e-logistics, e-services, e-administration and e-education have become common in the last few years. Another new term can be added: e-foresight [1-3]. It can be defined as the process of foresight research intended to identify the priority innovative technologies and strategic development tracks in a given research area, involving the use of the Internet. On the one hand, e-foresight focuses on supporting the work of foresight research teams. On the other hand, it gives freedom to the trade experts participating in survey research who can work in more convenient time and place, which leads to faster, more efficient, and more effective obtaining of intermediate and final research results. The e-foresight process, defined as computer aided scientific forecasting and shaping of the future is aimed to achieve the following goals: development of knowledge-based economy, statistical improvement of the technology quality applied in domestic enterprises, and continuation of sustainable development.

The conducted domestic research [4] have demonstrated that Poland still is not very successful in developing a knowledge-based economy. The following indices were analysed: the Knowledge Economy Index (KEI), the Summary Innovation Index (SII), the inventiveness index, the percentage of the GDP spent on research and development, the share of high- and medium-technology products in the industrial production, and the share of high- and medium-technology products in total exports. The carried out analyses have demonstrated the presence of a technology gap between Poland's economy and the economies of developed countries which, with regards to knowledge-based economy, are lead by Finland. It was also demonstrated that in the economy of Poland, the sectors which are considered to be the so-call high-technology sectors and which constitute a part of knowledge-based economy are underdeveloped; also, it was found that the research and development sector is underinvested as the amounts spent on it by enterprises are several times smaller than in the leading countries and as research and development works are poorly used in practice. Considering the above, it is very important to strengthen the links between the science and the business, especially with respect to the statistical majority of companies present in the market, namely the small and medium-sized enterprises. They require guidance with regards to actions that will guarantee their success in the market. One of the necessary conditions for their success is to apply innovative, prospective technologies, among which are many technologies in the field of surface engineering. Materials surface engineering, which includes surface treatment and surface coating, is one of the most dynamically growing sectors of the economy in many technologically advanced countries. For example, according to source data for the year 2008, this particular sector constituted 8-10% of the German economy. Thus, one can assume that a similar situation should occur soon in the rapidly growing economy of Poland. The broadly defined surface treatment and surface coating are implemented in nearly all production sectors of the industry, which demonstrates good future prospects and can potentially significantly contribute to Poland’s economic growth. What must also be emphasised is the importance of ecology and the need to both prevent new pollution and eliminate the consequences of the present degradation of the natural environment. Care for the natural environment goes hand in hand with the notion of sustainable development, defined as [5] a process of integrating systemic, economic, and social activities while maintaining a balance in the nature and preserving the basic natural processes, with the interest of the future generations in mind.

A particularly important role among surface treatment processes and production of gradient materials is played by laser surface treatment methods. Such methods have been described both in international and domestic literature, in reference to selected engineering materials [6-18], and in the works of the Division of Materials Processing Technologies, Management, and Computer Techniques in Materials Science of the Institute of Engineering Materials and Biomaterials of the Silesian University of Technology in Gliwice [19-36]. Laser treatment of surface layers of materials is aimed mostly to form their structure and properties, which takes place in the process of creating a chemically uniform, fine-crystalline surface layer, without changing the chemical composition of the material. Laser surface treatment contributes mostly to increasing the abrasion resistance and heat fatigue of the treated materials. It is also possible to improve the functional properties of materials by alloying the top layer of material with particles of hard phases of carbides, oxides, or nitrides. The advantages of laser surface treatment over other surface engineering methods are the short duration of the process, the flexibility and the precision of the process operations that can be performed on different types of materials, from hard-machinable, through soft, to brittle materials, with efficiency and accuracy which are often superior to those for the methods used so far. The ability to precisely adjust the process parameters, such as the speed of scanning of the surface with the laser beam, the power of the beam, the type and thickness of the alloying material, and the gas shield, makes it possible to obtain an alloy layer with the properties required for the particular application.

Hot-work alloy tool steels are still a widely used group of tool materials and are particularly interesting due to their low price and very good functional properties. The processes which are traditionally used in order to improve their characteristics are heat treatment, heat and chemical treatment, and heat and mechanical treatment, e.g. nitrogen hardening, carburizing, and boronizing. Laser treatment of the top layers of hot-work alloy tool steels appears to be an attractive alternative which allows for improving their functional properties, especially their hardness, abrasion resistance, and coarseness. Thanks to the benefits it provides, especially the high density of the laser radiation power, which allows for precise heating and controlled cooling of a small volume of the material, laser cladding and/or alloying enjoy a growing interest in many research centres world-wide [6-13].

The continuous importance of hot-work alloy tool steels to the industry and the advantages of laser surface treatment were the basis for the series of interdisciplinary foresight-materials science research aimed to determine the value, i.e. the attractiveness and the potential of laser treatment of hot-work alloy tool steel on the background of micro- and macroenvironment. The works also involved elaboration of the recommended strategies, strategic development tracks, and technology roadmaps for the analysed technologies, taking into account the impact of laser treatment on the quality, the structure, and the properties of surface layers of hot-work steels. The experimental materials science research covered the X40CrMoV5-1 and the 32CrMoV12-28 hot-work alloy tool steels which were laser remelted and/or alloyed using the NbC, TaC, TiC, WC, and VC carbide powders. The purpose of the research was to determine the impact of the alloying parameters on the refinement of the structure and the mechanical properties of the top layer, in particular on its hardness, abrasion resistance, and coarseness. The research was performed using the following diagnostics and measurement equipment: a scanning electron microscope, an optical microscope, a transmission electron microscope, a microhardness tester, a scratch tester, an X-ray diffractometer, an electron microprobe X-ray analyser and a device for testing of heat fatigue and abrasive resistance. The foresight-materials science research described herein constitute a part of broader own activities [2-3, 37-43] initiated to identify a set of priority innovative surface engineering technologies to be applied in practice in the industry, and to determine the strategic development directions in this field of science. The activities are intended to contribute to the achievement of the assumed objectives of the e-foresight [1], namely growth of knowledge-based economy, statistical improvement of the technology quality, and strengthening of the concept of sustainable development.

2. Applied research methods

The carried out interdisciplinary research using outworked methodology pertain mainly to technology foresight [44] and to surface engineering included in materials science. At certain stages of the conducted studies, also methods were used which come from artificial intelligence, statistics, IT technology, construction and exploitation of machines, as well as strategic [45], operational [46] and quality [47] management. The conducted research, according to the adopted methodology, include: selecting technology groups for experimental-comparative research, collecting expert opinions, carrying out a multi-criteria analysis and marking its results on the dendrological and meteorological matrix, determining strategies for technologies preceded by rescaling and objectivising test results using simple software, setting strategic development tracks for technologies, carrying out a series of specialist materials science experiments in experienced team [19-40] using a specialist diagnostic-measuring apparatus and the creation of technology roadmaps. According to the applied methodology of foresight-materials science research, several homogenous groups should be singled out from all analysed technologies in order to subject them to planned experimental-comparative nature research. To determine the objective values of given selected technologies or their groups a dendrological matrix of technology value is used. However, to determine the strength of positive and negative influence of the environment on a given technology a meteorological matrix of environment influence is used. The methodological construction of those both matrices refers to portfolio methods, and first of all to BCG matrix [48]. A ten-point universal scale of relative states was adopted for the purpose of evaluating technology groups with regard to their values and environmental influence. According to that scale the smallest value 1 corresponds to a minimum level, and the highest value 10 is the level of perfection.

The dendrological matrix of technology value [2] presents graphic results of evaluating specific technology groups, with special attention paid to the potential constituting the real objective value of a given technology and to the attractiveness reflecting how a given technology is subjectively perceived among its potential users. The potential of a given technology group expressed through a ten-point universal scale of relative states, marked on the horizontal scale of the dendrological matrix is the result of a multi-criteria analysis carried out based on an expert opinions. On the vertical scale of the dendrological matrix the level of attractiveness was marked of a given technology group which is the mean weighed expert opinions based on detailed criteria. Depending on the type of potential and level of attractiveness determined as part of the expert opinions, a given technology may be placed in one of the quarters of the matrix. In Table 1 the quarters distinguished in the dendrological matrix of technology value are presented.

Table 1. *The quarters of the dendrological matrix of technology value [38]*

Factors		Potential	
		Low	High
Attractiveness	High	A **quaking cypress** which is technology with a limited potential, but highly attractive, what causes that a success of technology is possible	A **wide-stretching oak** which corresponds to the best possible situation in which the analysed technology has both a huge potential and huge attractiveness, which is a guarantee of a future success
	Low	A **sparing aspen** which is technology with a limited potential and limited attractiveness in the range, which a future success is unlikely	A **rooted dwarf mountain pine** which is technology with limited attractiveness, but a high potential, so that its future success is possible

The meteorological matrix of environment influence [2] presents graphic results of evaluating the impact of external factors on specific technology group which had been divided into difficulties with a negative impact and chances which positively influence the analysed technologies. The testing of expert opinions on the subject of positive and negative factors which influence specific technologies was carried out based on a survey pertaining to the micro- and macroenvironment. External difficulties expressed with the use of a ten-point universal scale of relative states (from 1 to 10), which are the result of a multi-criteria analysis conducted based on the expert opinions, have been placed on the horizontal scale of the meteorological matrix. On the other hand, chances, i.e. positive environment factors being a mean weighed expert opinions based on detailed criteria, were placed on the analysed vertical scale. Depending on the level of influence of positive and negative environment factors on the analysed technology, determined as part of the expert opinions on a ten-point scale, it is placed in one of the matrix quarters. In Table 2 the quarters distinguished in the meteorological matrix of environment influence are presented.

Table 2. *The quarters of the meteorological matrix of environment influence [38]*

Factors		Difficulties	
		A small number	A large number
Chances	A large number	**Sunny spring** being the best option denoting friendly environment with lots of opportunities and a little number of difficulties, which means that the success of given technology is guaranteed	**Hot summer** corresponding to a situation in which the environment brings a lot of opportunities, which, however, are accompanied by many difficulties, meaning that the success of technology in the given circumstances is possible, but is a subject to the risk
	A small number	**Rainy autumn** corresponding to the neutral position, in which for given technology traps do not wait, but also the environment does not give too many opportunities	**Frosty winter** corresponding to the worst possible situation in which the environment brings a large number of problems and few opportunities, which means that success in a given environment is difficult or impossible to achieve

A **matrix of strategies for technologies** includes the research results transformed from a dendrological matrix of technology value, as well as a meteorological matrix of environment influence. A matrix of strategies for technologies consists of sixteen fields corresponding to each set of versions resulting from the combination of the types of technology and the types of environments. To facilitate the transfer of specific numeric values from the dendrological matrix [2x2] and the meteorological matrix [2x2] to the matrix of strategies for technologies with the dimensions of [4x4], mathematical relations and simple software were formulated [2] which enable the rescaling and objectivising of test results.

The **strategic development tracks** for analysed technologies/ technology group forecast given technology development successively in each five years during future twenty years being the time horizon of carried out research. The strategic development tracks in three versions: optimistic, pessimistic and most possible ones, were prepared. Also, they were visualised against a background of a matrix of strategies for technologies.

Table 3.*Chemical composition of the tested hot-work alloy tool steel*

Steel grade	Mass concentration of elements, %								
	C	Mn	Si	P	S	Cr	W	Mo	V
X40CrMoV5-1	0.41	0.44	1.09	0.015	0.010	5.40	0.01	1.41	0.95
32CrMoV12-28	0.308	0.37	0.25	0.020	0.002	2.95	–	2.70	0.535

A **series of materials science research** using specialised diagnostic and measurement equipment were carried out in order to precise the value of the potential and attractiveness of laser treatment of hot-work alloy tool steels. Tests were undertaken on the samples made of hot-work alloy tool steel: X40CrMoV5-1 and 32CrMoV12-28 with the chemical composition as provided in Table 3. The material for tests was poured into an ingot of approx. 250 kg after being melted in an electric vacuum furnace at the pressure of approx. 1 Pa and then was subjected to preliminary forging into rods with the diameter of 76 mm and 3 m long. The rods were next soft annealed to ensure good workability and uniform carbides distribution in the matrix. Samples were made by machining and the samples next underwent standard heat treatment (selected acc. to product sheets) including quenching and double tempering. X40CrMoV5-1 steel was austenitised in a vacuum furnace at 1020°C with annealing lasting 30 min. Two 30 min. isothermal intervals were made while heating to the austenitising temperature, the first one at 640°C and the other at 840°C. The samples were tempered twice after quenching, each time for 2 h at 560°C, and then at 510ºC. 32CrMoV12-28 steel was austenitised at 1040ºC, with annealing for 30 min. Two isothermal intervals were made while heating to the austenitising temperature, the first one at 585ºC, and then 850ºC. Double tempering for 2 hours was made after quenching at 550ºC, and then 510^{o} C. The samples after heat treatment were sand blasted and worked mechanically with a magnetic grinder. Special heed was paid to preventing from creating microcracks that could have disqualified a sample for further testing. Approx. 0.05 mm thick powder coatings were applied onto to the degreased surfaces of the samples in form of paste containing, respectively, tungsten carbide, niobium carbide NbC, vanadium carbide VC, titanium carbide TiC or tantalum carbide TaC bonded with inorganic binder in form of silicate water glass with the composition of Na_4SiO_4+$Na_2Si_2O_5$. The selected properties of powders are shown in Table 4, and the data in Figures 1-4 shows the topography of the selected powders used for the laser alloying of the tested steels. The laser cladding or laser alloying of the following hot-work alloy tool steel grades: X40CrMoV5-1 and 32CrMoV12-28 was carried out using a SINAR DL 020 High-Power Diode Laser (HPDL). Its technical specifications are provided in Table 5. The laser cladding or alloying processes were performed at a constant speed of 0.5 m/min with the process progress at such speed being stable, changing the laser beam power within 1.2-2.3 kW. A protected atmosphere was used to secure the melting area from the access of air and shielding gas (argon) through a ϕ 12 mm round nozzle was supplied for the purpose at a rate of 20 l/min. It was found based on the tests, including structural and hardness tests and a qualitative X-ray phase analysis, that it is advantageous to introduce the following ceramic powders to improve the functional properties of the surface layer: vanadium carbide, wolfram carbide, titanium carbide, tantalum carbide and niobium carbide; however, if oxide and nitride powders are introduced to the surface layer of hot-work steel, this does not improve the tested properties or such powders are not introduced into the melted steel. For this reason it was not verified positively if it is reasonable to use oxide and nitride oxides. The greatest improvement in the properties of the steel surface layer was achieved using titanium carbide and vanadium carbide powders for laser alloying. The steel alloyed with the above powders imparts high hardness and low roughness of the laser-treated surface. Further tests were undertaken to select the powders ensuring the best properties to the steel surface layer after laser alloying, in particular resistance to abrasive wear for the metal-ceramic material configuration. The smallest mass loss in the metal - ceramic material configuration for the tested ceramic powders is seen for the steel alloyed with titanium carbide and vanadium carbide powders. The mass loss for the steel alloyed with wolfram carbide, niobium carbide and tantalum carbide powder is comparable to this for remelted steel. The abrasive wear resistance tests for the metal-metal configuration imitating tool work in industrial conditions (abrasion of matrices or forging tools) confirm the results of the previous tests. In such configuration, the steel surface layer produced as a result of alloying with vanadium carbide or titanium carbide exhibits greater abrasive resistance.

Table 4. *Selected properties of ceramic powders*

Coating Type	Hardness HV, GPa	Melting Point, °C	Density, g/cm^3	Thermal expansion coefficient α, $10^{-6}\cdot K^{-1}$
WC	2400	2730-2870	15.77	23.8
NbC	1800	3480-3610	7.6	7.6
VC	2600	2650-2830	5.81	7.5
TiC	3200	3065-3180	4.94	8.3
TaC	1600	3780-3985	14.5	7.8

Table 5. *Technical data of HPDL ROFIN DL 020 diode laser*

Parameter	Value
Length of laser radiation waves, nm	808±5
Output power of laser beam (constant radiation), W	2300
Power range, W	100-2300
Focal length of laser beam, mm	82 / 32
Focal point dimensions of laser beam, mm	1.8 x 6.8 / 1.8 x 3.8
Power density range in laser beam focal plane, kW/cm^2	0.8-36.5

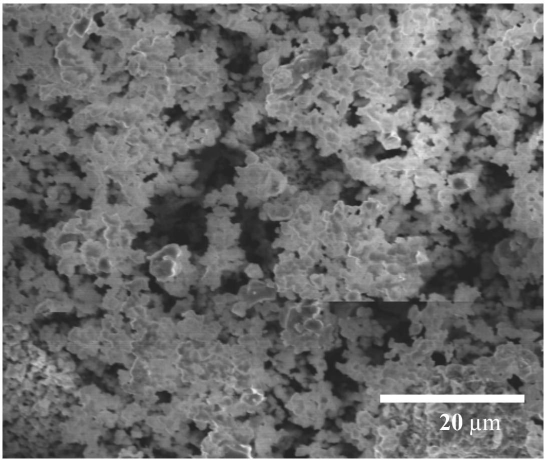


Figure 1. *Topography of tantalum carbide powder (TaC) used for the tests (SEM)*

Roughness was measured with a Surtronic 3+ contact profilometer by Taylor-Hobson. The samples' surface was cleaned with acetone, and then an average arithmetic roughness profile deviation R_a was measured. The structure of the tested steels was observed with a Leica MEF4A light microscope in a light, dark and polarised field with the magnification of: 25-1000x and with a DSM-940 electron scanning microscope by Opton with the accelerating voltage of 20 kV, using a detector of secondary electrons and backscattered electrons.

The structures were photographed with a Leica - Qwin computer-aided image analysis system. A qualitative X-ray microanalysis and a surface and linear distribution analysis of alloy elements in the samples of the tested steels in the quenched condition was performed with a DSM-940 scanning microscope by Opton fitted with a LINK ISIS energy dispersive spectrometer (EDS) by Oxford at the accelerating voltage of 20 kV. The direct structure tests in a light field and in a dark field and diffraction tests enabling a phase analysis of the selected micro-area were carried out in a JEM 3010UHR transmission electron microscope by JEOL, at the accelerating voltage of 300 kV.

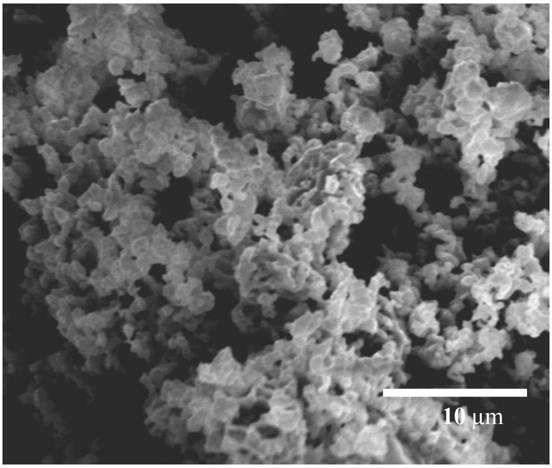


Figure 2. *Topography of niobium carbide powder (NbC) used for the tests (SEM)*

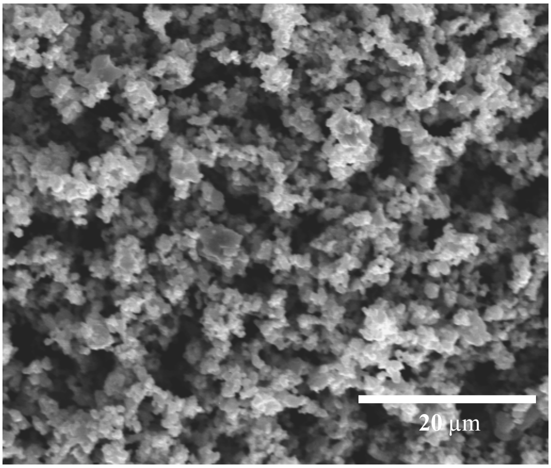


Figure 3. *Topography of vanadium carbide powder (VC) used for the tests (SEM)*

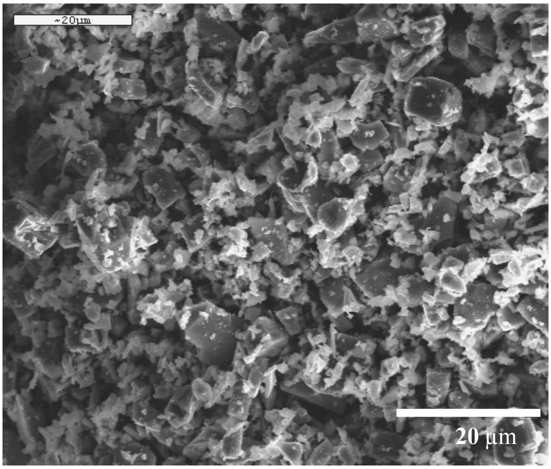


Figure 4. *Topography of titanium carbide powder (TiC) used for the tests (SEM)*

Hardness measurements were made on the surface layers of the samples cleaned mechanically using a Zwick ZHR 4150TK hardness tester with an electronic sensor fitted allowing to read hardness directly with Rockwell's method. The tests were made for all the laser-cladded or alloyed samples and also for the sample made of the tested steels subjected to conventional heat treatment. The wear resistance of the surface layers achieved from laser cladding or alloying using the following carbide powders: WC, NbC, TaC, VC and TaC was determined with an abrasability test acc. to the American standard – ASTM G65-04. The data presented as a quotient of the mass loss of the laser-remelted or alloyed sample with carbide powder in respect of the mass of the sample heat-treated conventionally. It was concluded based on the tests results that a relationship exists for the tested steels between the laser power used for alloying and the resistance to abrasive wear. The abrasive wear resistance tests with the metal – ceramic material method were carried out at a stand designed at the Welding Department of the Silesian University of Technology, Gliwice, in accordance with ASTM G65 standard. The mass loss according to laser power used for cladding or alloying and according to the alloying material was measured with Wa 33 PRL T A13/1 laboratory balance with the accuracy of up to 0.0001 g. The samples were weighed before and after the abrasion test.

A set of the **technology roadmaps** [2, 3, 40] on the basis of source data received during carried out experimental-comparative research were prepared. The layout of the technology roadmap created for the purpose of the realised research corresponds to the first quarter of the

Cartesian coordinate system. Three time intervals were placed on the horizontal axis, pertaining to: the situation as of today, in ten years' and in twenty years' time. The time horizon of all the research placed on the technology roadmap equals 20 years and is adequate to the dynamics of changes occurring in the surface engineering area. On the vertical axis of the technology roadmap seven main layers were placed corresponding to a specific question pertaining to the analysed scope. Each of the main layers has been additionally divided into more detailed sub-layers. In addition, the technology roadmap presents relations between its specific layers and sub-layers, with a division into: cause-and-effect relations, capital relations, time correlations and two-way flows of data and/or resources, visualised using different types of arrows. The technology roadmap is a universal tool which enables presenting, in a unified and clear format, different types of internal and external factors directly and indirectly characterizing a given technology, taking into account the ways of influence, interdependencies and the change of specific factors over time. When needed, the technology roadmap may be supplemented and expanded by additional sub-layers, adapting it, e.g. to the specificity of the carried out scientific-research studies, the requirements of a given industrial field or the enterprise size.

Using the adopted set of interdisciplinary methods, a research cycle was performed; the results of the research are presented in the present chapter. The most important among them are those related to evaluation of the potential and the attractiveness of the technology group in question on the background of their environment, which was performed based on the opinions of key experts, expressed in a ten-point universal scale of relative states. The next step was to formulate the recommended strategy for a given technology and the forecast strategic development tracks (sub-chapter 3). The results of the series of materials science experiments intended to determine the impact of the selected laser treatment parameters on the structure and the characteristics of the hot-work alloy tool steels in question which were laser-melted and/or alloyed are presented in sub-chapter 4 of the chapter. In particular, the sub-chapter describes the results of the metallographic structure tests involving scanning electron microscopy, hardness and micro-hardness tests, and micro-analysis of the chemical composition. Sub-chapter 5 of the chapter presents the roadmaps for the technology group in question, prepared based on the results of the interdisciplinary experimental and comparative research which was performed. The technology roadmaps show, in a uniform and clear format, the internal and external factors which directly characterize the individual technology group, taking into account the interactions, the mutual relations, and the change of the individual factors in time.

3. Evaluated value and development directions of analysed technologies

Taking as a criterion of the division, a type of powder deposited to the substrate, in order to carry out comparative and experimental works, five homogeneous groups were isolated from the analysed technologies in turn:

(A) hot-work alloy tool steels which underwent laser treatment by NbC niobium carbide;
(B) hot-work alloy tool steels which underwent laser treatment by TaC tantalum carbide;
(C) hot-work alloy tool steels which underwent laser treatment by TiC titanium carbide;
(D) hot-work alloy tool steels which underwent laser treatment by VC vanadium carbide;
(E) hot-work alloy tool steels which underwent laser treatment by WC tungsten carbide.

The individual technology group were evaluated by key experts with regards to their attractiveness and potential, using a ten-point universal scale of relative states. Using a multi-criterion analysis, the weighted average was calculated of the detailed criteria selected within the attractiveness and the potential, and the results obtained for the individual technology group were charted on the dendrological matrix of technology value (Fig. 5). As a result of the analysis, all technology group were classified in the most promising quarter of the matrix, which covered technologies with a great potential and high attractiveness, called a patulous oak tree. The best result with regards to the internal potential, which demonstrates the objective value of the technology, was achieved by the C (8.05, 7.75) technology group, which includes laser treatment of hot-work alloy tool steel using TiC titanium carbide powder. The technology group which was found to be the most attractive was laser treatment of hot-work alloy tool steels using VC vanadium carbide powder, designated as D (6.95, 8.20), which should lead to the greatest interest in this technology group among potential buyers and users.

The meteorological matrix of environmental influence has been used to evaluate the positive and negative impact of the environment on the individual technology group. The results of the multi-criterion analysis performed on the opinions of experts who filled out a survey form comprising several dozen questions, were charted on the meteorological matrix (Fig. 6). The research indicates that the most advantageous environmental conditions, corresponding to early spring, are associated with the following technology group: C (5.10, 5.72) – laser treatment of hot-work alloy tool steels using TiC titanium carbide powder, and

D (5.37, 5.81) – laser treatment using VC vanadium carbide powder. Hot summer, which brings both numerous opportunities and numerous difficulties, is the environment for the A (6.68, 5.73) technology group involving laser treatment of hot-work alloy tool steel using NbC niobium carbide powder and the B (6.10, 6.31) technology group involving laser treatment using TaC tantalum carbide powder. Almost in the very centre of the matrix, yet in the field of rainy autumn with few opportunities and difficulties, was the E (5.42, 5.49) technology group involving laser treatment of hot-work alloy tool steel using WC tungsten carbide powder.

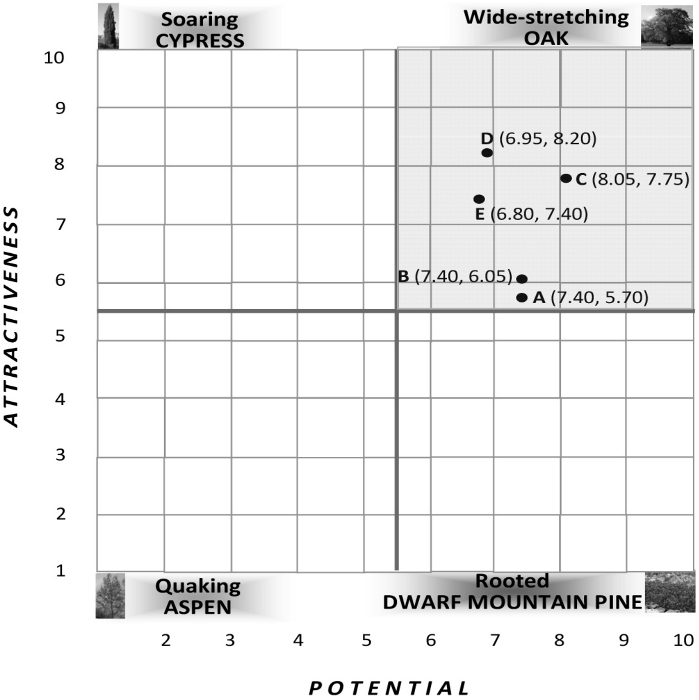


Figure 5. *The dendrological matrix of technology value for the laser treatment of hot-work alloy tool steels using NbC (A), TaC (B), TiC (C), VC (D) and WC (E) carbide powders*

At the next stage of research, the results of the research, presented in a graphic form with a dendrological matrix of technology value and the meteorological matrix of environmental influence, were charted on the matrix of strategies for technologies (Fig. 7). The matrix graphically depicts the place of the different groups of hot-work alloy tool steel laser treatment technologies, taking into account their value, which is the product of their potential and attractiveness, and the strength of the environmental influence, and indicates the appropriate strategy.

The transfer of specific numerical values from the dendrological matrix and the meteorological matrix into the matrix of strategies for technologies with different dimensions was performed using mathematical relations and simple computer software based on such relations, which allowed for scaling and objectivizing the research results [2].

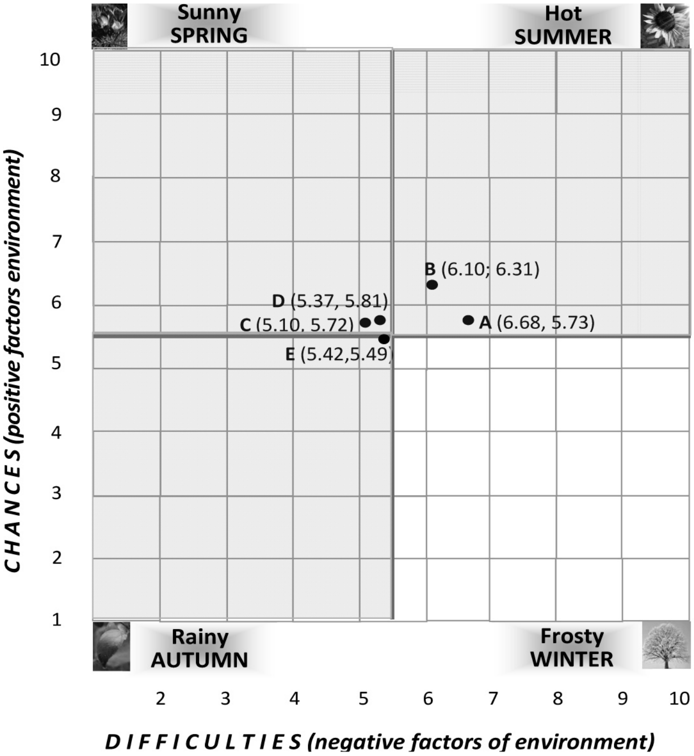


Figure 6. *The meteorological matrix of environment influence for the laser treatment of hot-work alloy tool steels using NbC (A), TaC (B), TiC (C), VC (D) and WC (E) carbide powders*

The C (8.79, 7.86) technology group, involving laser treatment of hot-work alloy tool steel using TiC titanium carbide powder and the D (8.61, 7.80) technology group, involving laser treatment using VC vanadium carbide powder are recommended to use the strategy of an oak in spring. The strategy consists in developing, strengthening and implementing an attractive technology with large potential in industrial practical applications in order to achieve spectacular success. As for the A (8.13, 6.15) technology group, involving laser treatment of hot-work alloy tool steels using NbC niobium carbide powder and the B (8.22, 6.44) technology group,

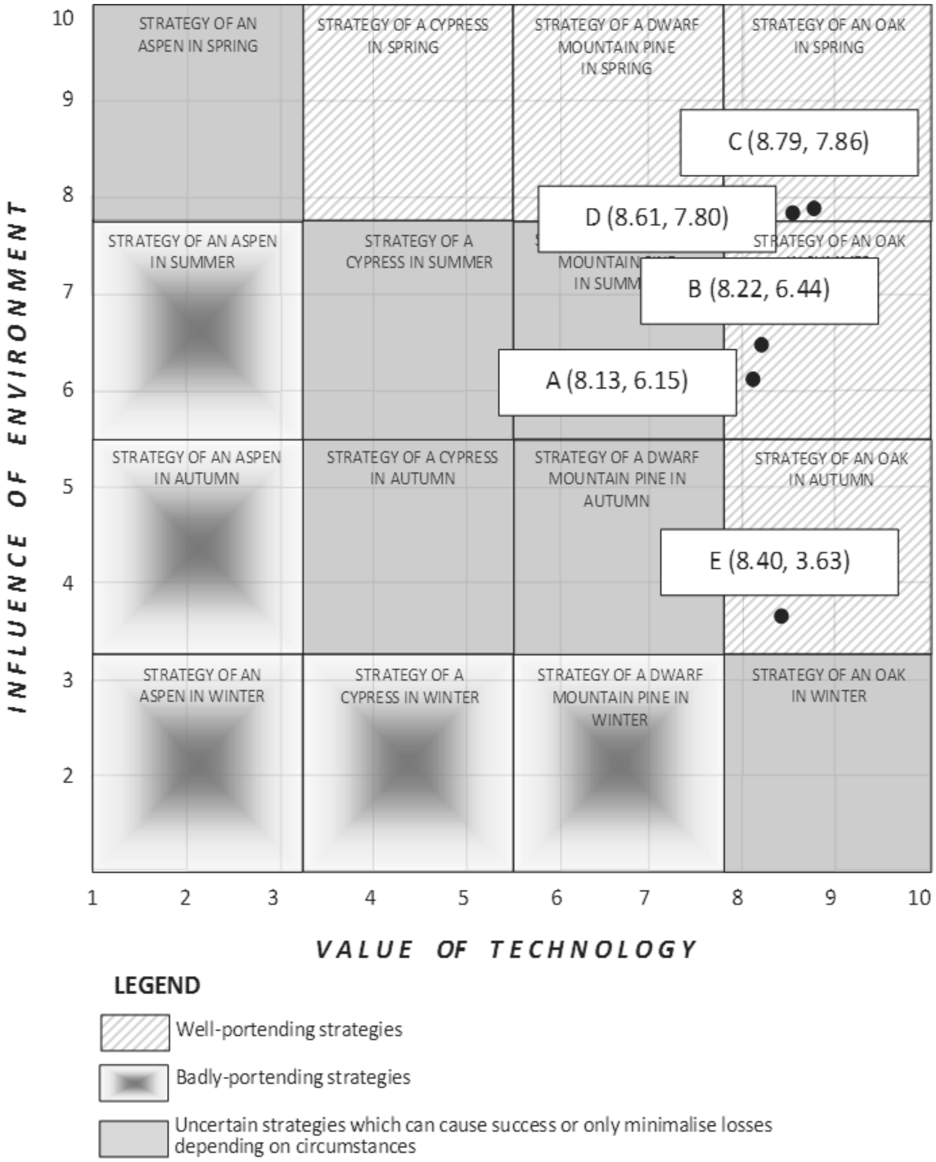


Figure 7. *The matrix of strategies for technology called the laser treatment of hot-work alloy tool steels using NbC (A), TaC (B), TiC (C), VC (D) and WC (E) carbide powders*

involving laser treatment using TaC tantalum carbide powder the strategy of an oak in summer was recommended. The strategy assumes taking advantage of the attractiveness and the potential of the technologies in a risky environment and avoiding possible difficulties, while making the product suitable to meet the requirements of the customers, based on a thorough marketing research. The E (8.40, 3.63) technology group involving laser treatment of hot-work alloy tool steels using WC tungsten carbide requires the oak in the autumn strategy. This strategy involves achieving success with an attractive and stable technology in a reliable market while searching for new markets customer groups and products that can be made using this technology.

The next stage of the research consists in defining, based on experts' opinions, the strategic development tracks for the individual technologies/technology group, which constitute a forecast of their development in the years 2015, 2020, 2025 and 2030, and according to three scenarios: optimistic, pessimistic, and the most likely, and in their display on the background of the matrix of strategies for technologies.

The case selected to be presented in this chapter is the E technology group, involving laser treatment of hot-work alloy tool steels using WC tungsten carbide powder. It is shown in Figure 8, together with the anticipated strategic development tracks for this group according to three scenarios (optimistic, pessimistic, and the most probable), on the background of the matrix of strategies for technologies. The most probable strategic development track for the group of analysed technologies assumes that the neutral environmental conditions, with small number of both opportunities and risks, will be maintained, which will lead to a fairly slow strengthening of the potential and the attractiveness of the technology, which already have a high value. According to this forecast, the (B) technology group will remain in the oak in the autumn field until 2030. The optimistic development track for this technology group assumes that the environmental conditions will improve, which will result in a shift of this technology group in 2025 into the matrix field corresponding to the best possible strategic situation, that of an oak in the spring, where the technology group will stay until the end of the forecast period. The pessimistic scenario, depicted as the third strategic development track, for the technology group in question, assumes that the global crisis will become more severe and the present neutral environment will become more problematic. This will result in a shift of the technology group into the oak in the summer field in 2015. If the circumstances are not advantageous, later (in 2025), the technology group involving laser treatment of hot-work alloy tool steels using WC tungsten carbide powders may shift into the oak in the winter field, due to the higher competitiveness in the sector and the need to intensify the search of new markets, customers, and products that can be made using this technology. The numerical values which result from the research performed for the five analysed technology group, which correspond to the different types of applied powders, are shown in Table 6. Because the different technology group are located in the central part of the meteorological matrix, in many cases despite the fairly small differences in the presented numerical values, it is recommended to use different approaches towards the different fields of the matrices used as an evaluation tool.

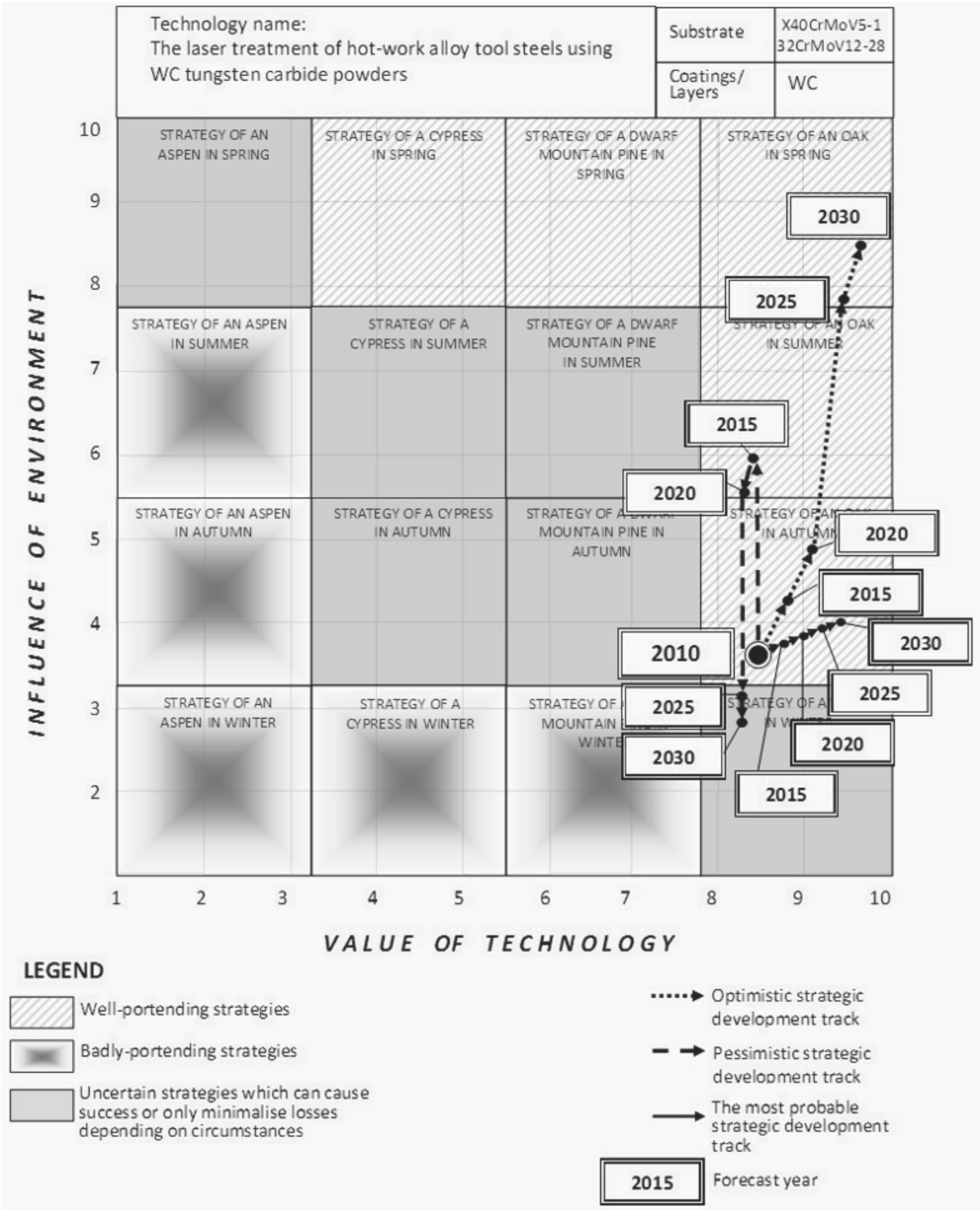


Figure 8. *The strategic development tracks for the (E) demonstration technology called the laser treatment of hot-work alloy tool steels using WC tungsten carbide powders*

Table 6. *Strategic development tracks of laser treatment of hot-work alloy tool steels using carbide powders. Types of strategic development tracks: (O) – optimistic, (P) – pessimistic; (MP) – the most probable*

No.	Technology name	Steady state 2010	Type of strategic development tracks	Years			
				2015	2020	2025	2030
1.	The laser treatment of NbC niobium carbide powders in the surface of hot-work alloy tool steels	Strategy of an oak in summer A (8.1, 6.2)	(O)	(8.3, 6.5)	(8.5, 7.0)	(8.7, 8.0)	(8.8, 8.2)
			(P)	(8.1, 5.7)	(8.1, 3.0)	(8.0, 2.8)	(8.0, 2.6)
			(MP)	(8.2, 5.8)	(8.3, 3.5)	(8.5, 4.2)	(8.6, 4.8)
2.	The laser treatment of TaC tantalum carbide powders in the surface of hot-work alloy tool steels	Strategy of an oak in summer B (8.2, 6.4)	(O)	(8.4, 6.8)	(8.6, 7.4)	(8.8, 8.2)	(9.0, 8.4)
			(P)	(8.3, 5.8)	(8.3, 3.1)	(8.2, 2.9)	(8.2, 2.7)
			(MP)	(8.3, 5.9)	(8.4, 3.7)	(8.6, 4.4)	(8.8, 4.9)
3.	The laser treatment of TiC titanium carbide powders in the surface of hot-work alloy tool steels	Strategy of an oak in spring C (8.8, 7.9)	(O)	(9.0, 8.2)	(9.2 8.4)	(9.4, 8.6)	(9.7, 8.8)
			(P)	(8.8, 7.2)	(8.8, 6.2)	(8.8, 5.9)	(8.8, 3.2)
			(MP)	(8.9, 5.7)	(9.0, 6.3)	(9.1, 8.1)	(9.2, 8.5)
4.	The laser treatment of VC vanadium niobium carbide powders in the surface of hot-work alloy tool steels	Strategy of an oak in spring D (8.6, 7.8)	(O)	(8.8, 8.2)	(9.0 8.4)	(9.2, 8.6)	(9.4, 8.8)
			(P)	(8.6, 7.1)	(8.6, 6.0)	(8.6, 5.8)	(8.6, 3.1)
			(MP)	(8.7, 5.7)	(8.8, 6.2)	(8.9, 7.9)	(9.1, 8.3)
5.	The laser treatment of WC tungsten carbide powders in the surface of hot-work alloy tool steels	Strategy of an oak in autumn E (8.4, 3.6)	(O)	(8.8, 4.3)	(9.2, 4.8)	(9.4, 7.8)	(9.6, 8.5)
			(P)	(8.4, 6.0)	(8.3, 5.6)	(8.3, 3.1)	(8.3, 2.8)
			(MP)	(8.7, 3.7)	(9.0, 3.8)	(9.2, 3.9)	(9.4, 4.0)

4. Received results of materials science research

In order to precise the value of the potential and attractiveness of laser treatment of hot-work alloy tool steels a series of materials science research using specialised diagnostic and measurement equipment were carried out. The outcarried experimental works bowling down to the laser treatment of five different carbide powders of the X40CrMoV5-1 and 32CrMoV12-28 hot-work alloy tool steels the influence of parameters process like power laser and using powders on shape and surface topography were shown. A melted zone (RZ), heat-affected zone (HAZ) and transition limits between the melted zone and heat-affected zone and between the heat-affected zone and the virgin material (VM) exist in each laser cladded or alloyed surface layer of the tested steel (Figs. 9-12). The thickness of the melted zone and the heat-affected zone depends on the laser beam power. The zone thickness increases along with an increase in laser power with alloying speed and alloying coating thickness being constant. Figures 13 and 14 present the effect of laser power on the thickness of the tested steels' melted zone thickness and heat-affected zone.

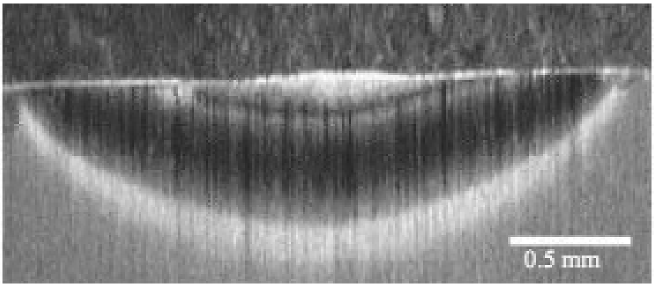


Figure 9. *Surface layer of X40CrMoV5-1 steel after laser cladding, laser power of 1.2 Kw*

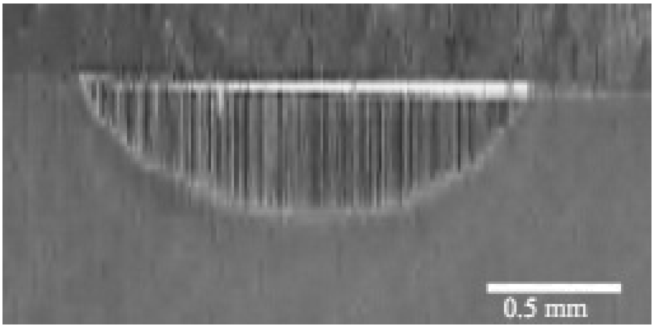


Figure 10. *Surface layer of 32CrMoV12-28 steel after laser cladding, laser power of 1.2 kW*

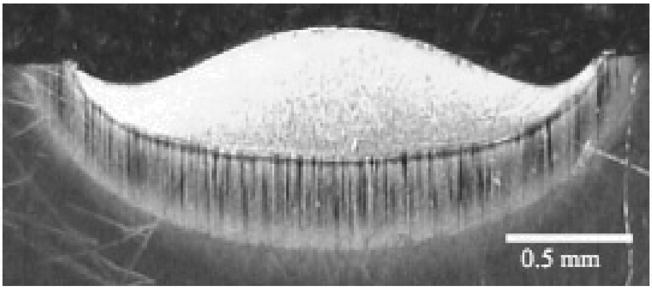


Figure 11. *Surface layer of X40CrMoV5-1 steel after laser alloying with tantalum carbide, laser power of 2.3 kW*

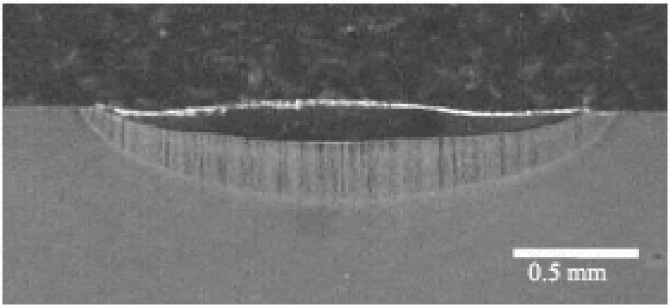


Figure 12. *Surface layer of 32CrMoV12-28 steel after laser alloying with tungsten carbide, laser power of 2.0 kW*

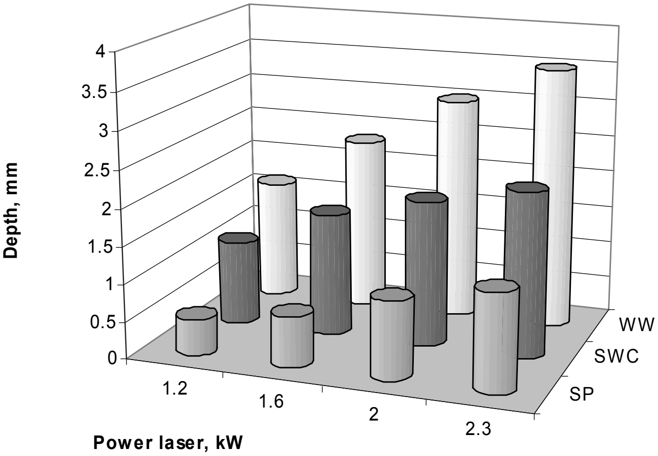


Figure 13. *The effect of laser power on the thickness of RZ and HAZ of X40CrMoV5-1 steel after laser alloying with TaC within the laser power of 1.2-2.3 kW*

The characteristic type of topography and the bead face shape formed from cladding or alloying the surface layers of hot-work X40CrMoV5-1 and 32CrMoV12-28 steel with a HPDL diode microscope within the power range of 1.2-2.3 kW were found based on the observations in a light microscope. The alloying conditions and in particular the laser beam power and the alloying material type have an important effect on the bead face shape. The surface layers produced in the cladding process are characterised by smaller roughness, more regular cladding shape and no cracks as compared to the steel alloyed with carbide powders.

Figures 15-18 show the face view after the laser cladding and alloying of the surface layer depending on the type of the carbide powder and laser power used. Surface roughness is increasing along with rising laser power when carbide powders for alloying are used and when cladding the surface only. Due to small laser beam power (1.2 and 1.6 kW) used for alloying, some grains of the alloying material remain on the surface, thus increasing its roughness, and the high scanning speed influences the specific steel surface shape as a result of fast metal crystallisation according to the heat evacuation direction.

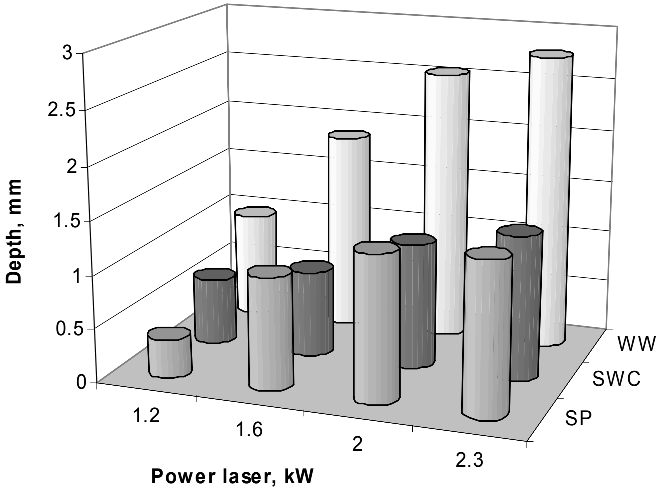


Figure 14. *The effect of laser power on the thickness of RZ and HAZ of 32CrMov12-28 steel after laser alloying with TaC within the laser power of 1.2-2.3 kW*

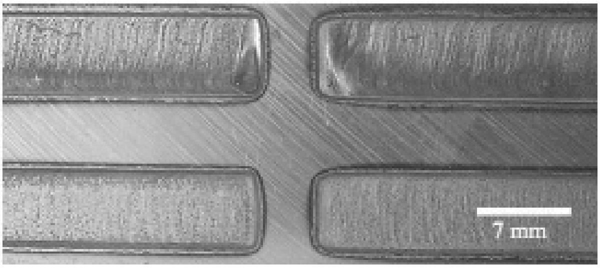


Figure 15. *Face view after laser cladding, X40CrMoV5-1 steel, laser power of 1.2-2.3 kW*

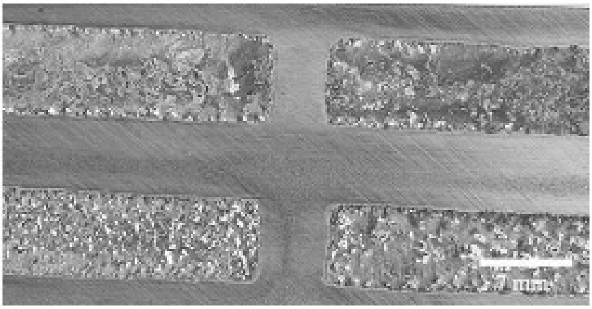


Figure 16. *Face view after laser alloying with tungsten carbide, X40CrMoV5-1 steel, laser power of 1.2-2.3 kW*

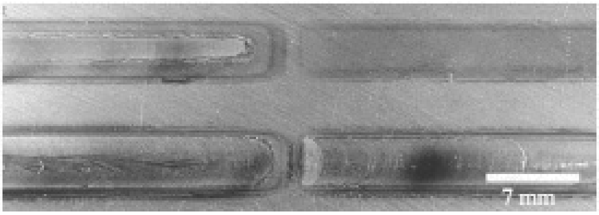


Figure 17. *Face view after laser cladding, 32CrMoV12-28 steel, laser power of 1.2-2.3 kW*

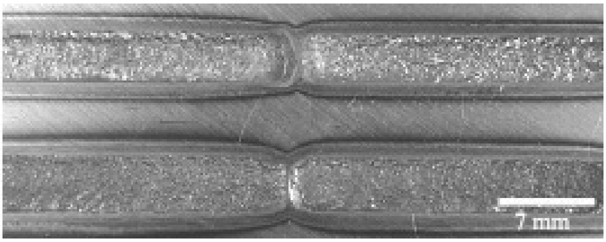


Figure 18. *Face view after laser alloying with vanadium carbide, 32CrMoV12-28 steel, laser power of 1.2-2.3 kW*

Figures 19 and 20 present the effect of laser power on the roughness parameter value for the surface layers of laser-remelted or alloyed steels. Surface roughness is growing along with higher laser beam power as a result of laser cladding or alloying with carbide powders.

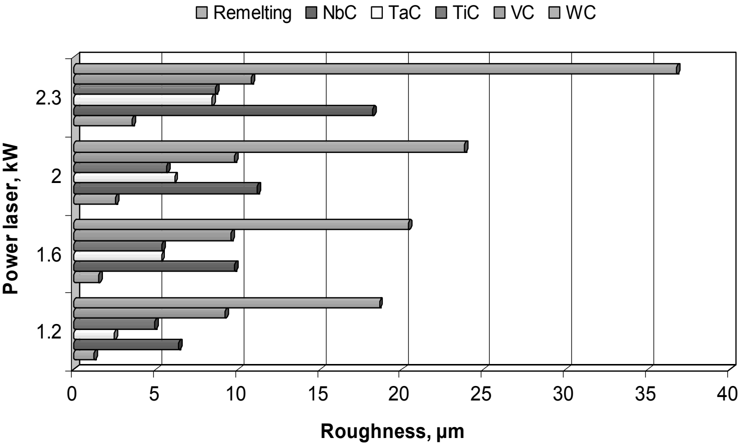


Figure 19. *Average roughness of surface layer for X40CrMoV5-1 steel remelted with laser or alloyed with carbide powders with a 1.2-2.3 kW laser*

It was found based on the observations with a light microscope (Figs. 21-24) that the melted zone of the steel subjected to laser cladding and alloying is of a dendritic structure

(Figs. 25 and 26). The steel structure after cladding and after alloying is characterised by areas with a very differentiated morphology connected with the solidification of the material.

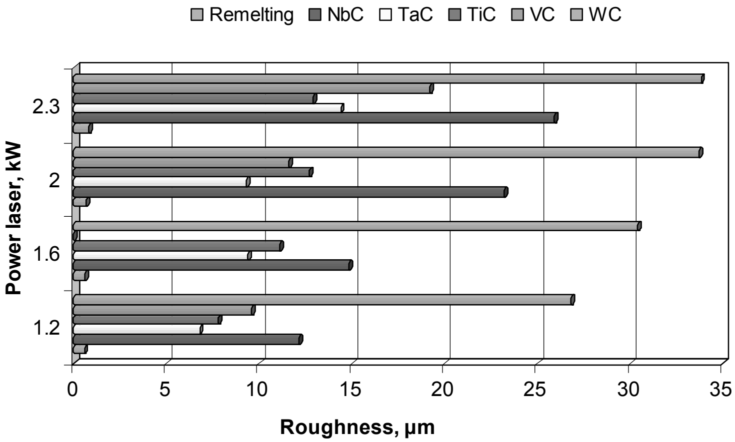


Figure 20. *Average roughness of surface layer for 32CrMoV12-28 remelted with laser or alloyed with carbide powders with a 1.2-2.3 kW laser*

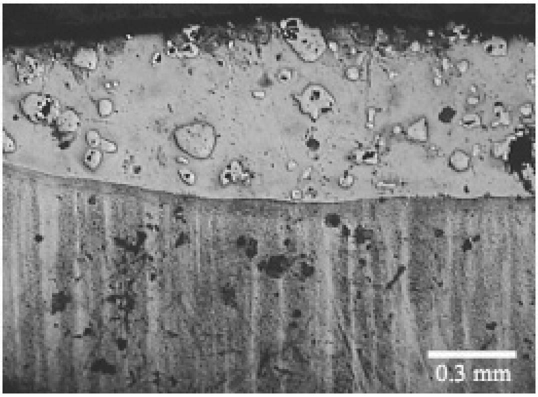


Figure 21. *View of surface layer section after laser alloying of X40CrMoV5-1 steel, tungsten carbide powder, laser power of 2.3 kW*

The clusters of unmelted alloying material carbides occur in the central area of the melted zone. The convective movements present during steel cladding and alloying are "freezing" due to the sudden solidification of the melted zone (Figs. 27 and 28).

The observations carried out with a scanning electron microscope have revealed that the surface layer of the tested X40CrMo5-1 steel subjected to laser cladding and alloying shows a zonal structure, especially the melted zone and the heat-affected zone (Figs. 29 and 30).

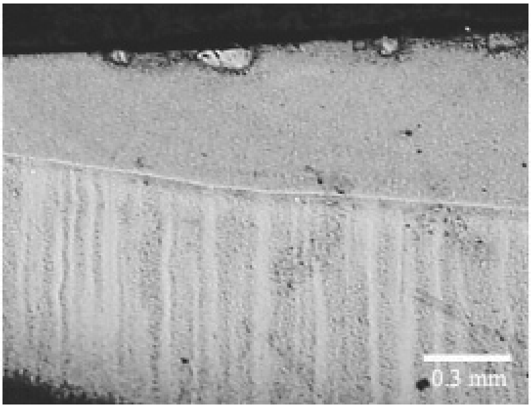


Figure 22. *View of surface layer section after laser alloying, X40CrMoV5-1 steel, vanadium carbide powder, laser power of 2.0 kW*

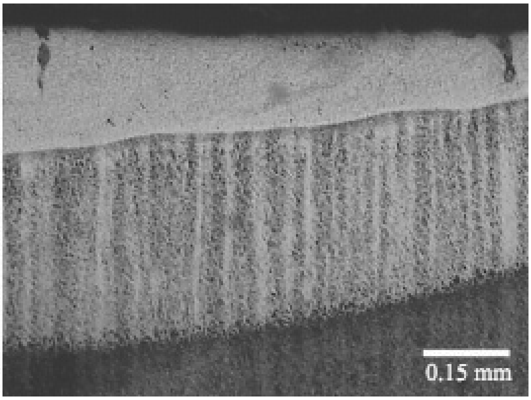


Figure 23. *View of surface layer section after laser alloying, 32CrMoV12-28 steel, vanadium carbide powder, laser power of 1.2 kW*

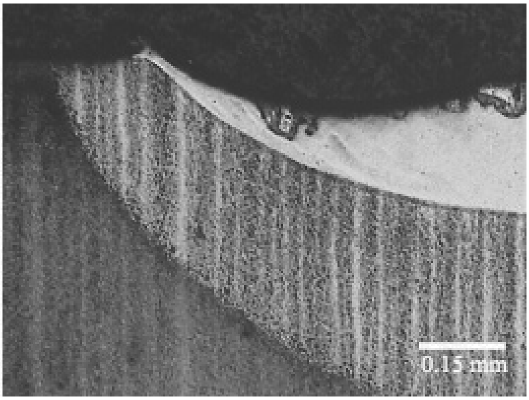


Figure 24. *View of surface layer section after laser alloying, 32CrMoV12-28 steel, vanadium carbide powder, laser power of 2.3 kW*

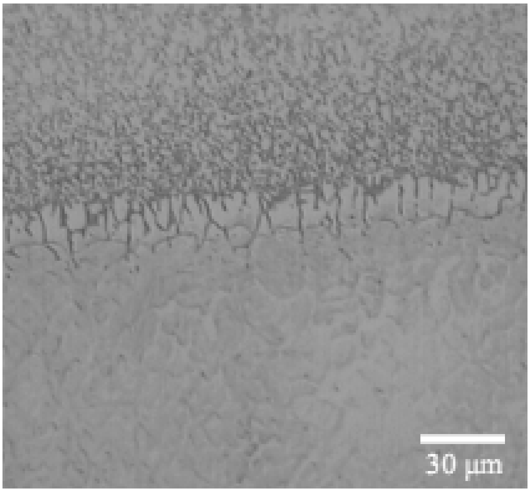


Figure 25. *Melted zone limit of X40CrMoV5-1 steel surface layer, after alloying with titanium carbide, laser power of 2.3 kW*

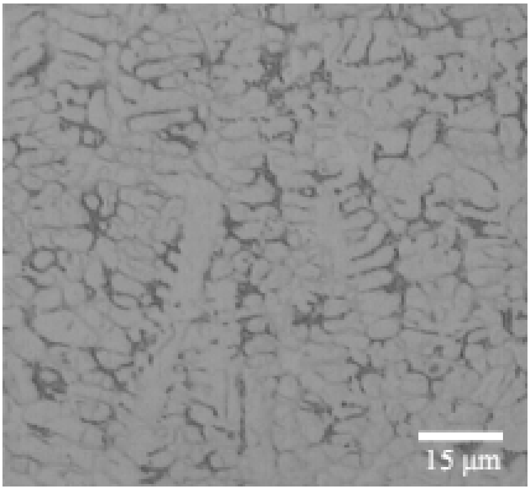


Figure 26. *Central zone of remelted surface layer of X40CrMoV5-1 steel after remelting, laser power of 2.3 kW*

The presence of the elements contained in the tested steel for X40CrMoV5-1 and 32CrMoV12-28W material was found as a result of a linear and local chemical composition analysis using a scattered X-ray radiation spectrometer performed on the lateral microsections of the surface layer remelted or alloyed with laser with different power rating. The presence of the elements contained in the surface layer formed due to alloying with carbide powders was also concluded on the basis of the tests. The local analysis of chemical composition confirms the presence of the elements contained in the tested X40CrMoV5-1 steel: C, Fe, Mn, Si, Cr, W, Mo, V and the elements originating from the alloying material. It was also found in case of 32CrMoV12-28 steel that the following elements are present: C, Fe, Mn, Si, Cr, W, Mo, V,

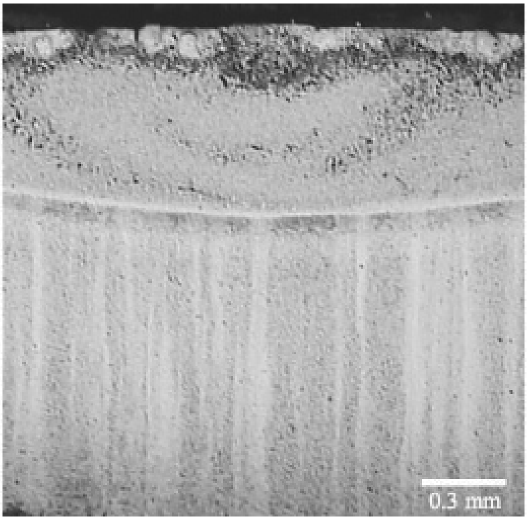


Figure 27. *Melted zone limit of the steel surface layer after alloying with vanadium carbide, laser power of 1.6 kW*

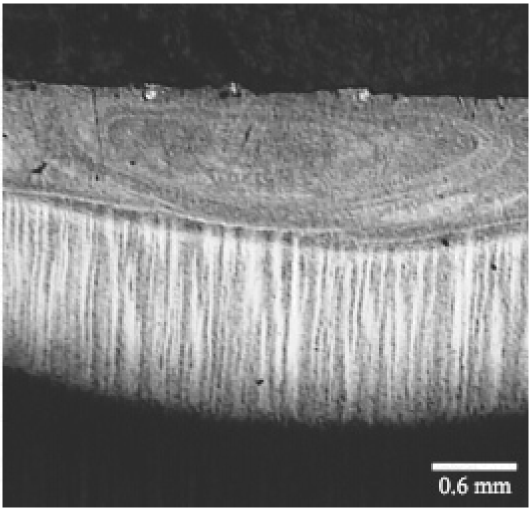


Figure 28. *Melted zone limit of the steel surface layer after alloying with titanium carbide, laser power of 2.0 kW*

however with a different proportion as appropriate for this material. The diagrams of concentration according to scattered radiation energy show the results of the local analysis in the micro-areas of the matrix and carbides (Figs. 31-36).

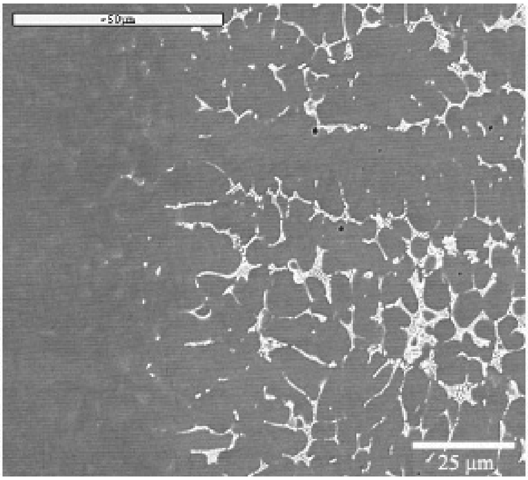


Figure 29. *Zonal structure of the surface layer of X40CrMo5-1 steel alloyed with TaC powder, the laser beam power of 1.6 kW*

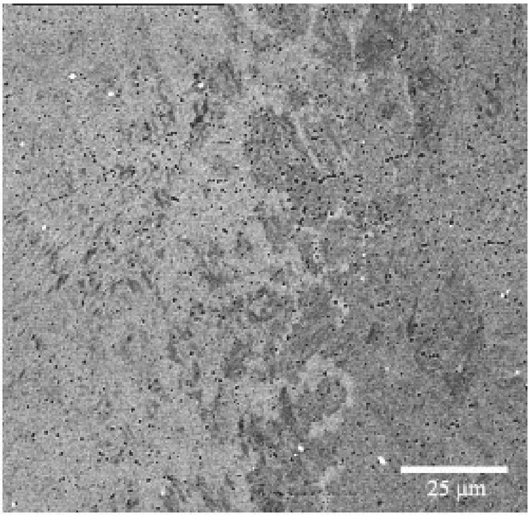


Figure 30. *Zonal structure of the surface layer of X40CrMo5-1 steel remelted with laser, the laser beam power of 1.2 kW*

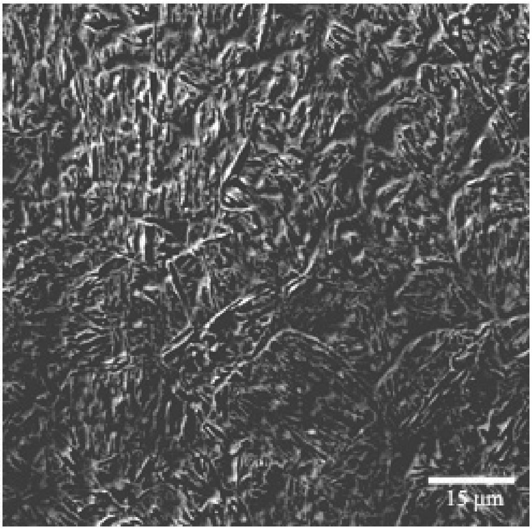


Figure 31. *Surface layer of steel after alloying with vanadium carbide VC powder, the laser beam power of 2.3 kW (SEM)*

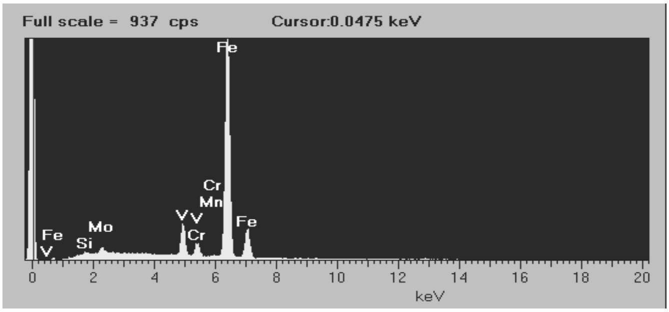


Figure 32. *Diagram of concentration according to energy for the dispersed X-ray radiation for the sample of 32CrMoV12-28 steel after laser alloying with VC vanadium powder*

The tests of thin foils made in a transmission electron microscope with X40CrMoV5-1 and 32CrMoV12-28 steel samples reveal that martensite constitutes the structure of this steel in a quenched and twice-tempered condition (Fig. 37), tempered with dispersion secretions of M_7C_3 carbide. It was found that the respective carbides used for alloying occur on the limits of grains based on the tests of thin foils made using the surface layer of hot-work tool steel alloyed with carbide powders (Figs. 37 and 38). Lath martensite with a high dislocation density constitutes the surface layer matrix after alloying. The tests with a transmission electron microscope have confirmed the presence of particles of all the types of carbides used for alloying: vanadium carbide, wolfram, titanium, niobium and tantalum. The size of the carbide particles found indicate a differentiated size - smaller than this would be shown by the grain size of the ceramic powder used for the tests. This indicates that the particles of carbide powders in the steel matrix have dissolved, however, a more thorough examination made in the future would have permitted to conclude to what extent the alloying material has dissolved in the matrix.

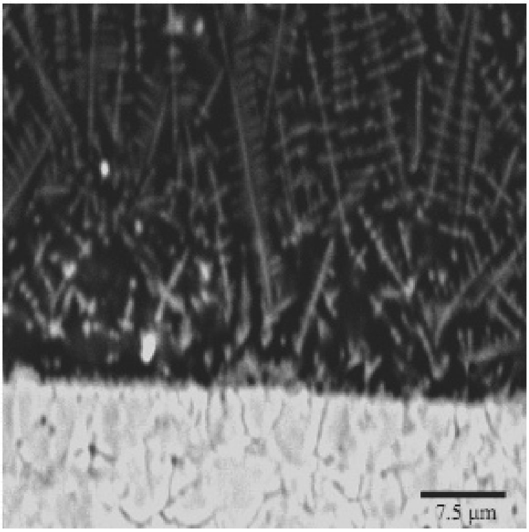


Figure 33. *Surface layer of 32CrMoV12-28 steel after alloying with VC powder, the laser beam power of 2.3 kW*

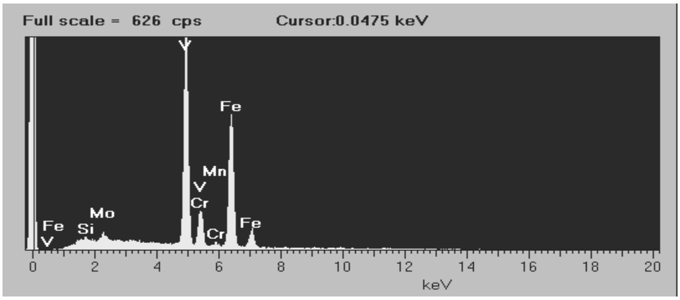


Figure 34. *Diagram of concentration according to scattered X-ray radiation energy for a 32CrMoV12-28 steel sample after laser alloying with VC vanadium powder*

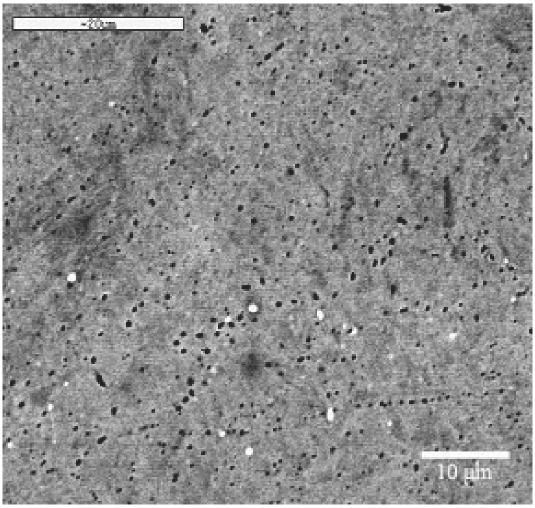


Figure 35. *Central zone of cladding the surface layer of X40CrMoV5-1 steel sample after cladding with laser, the laser beam power of 1.2 kW*

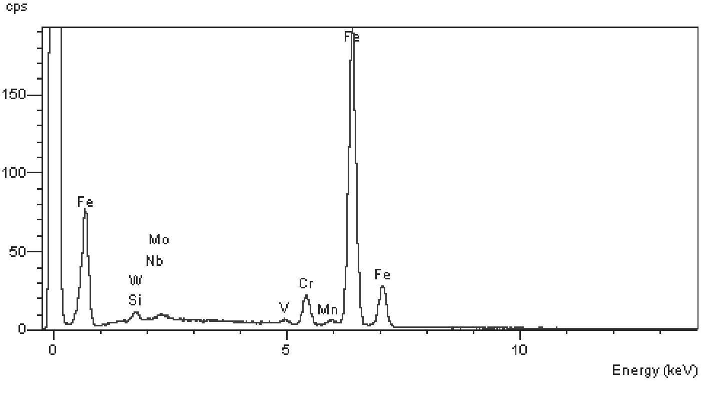


Figure 36. *Diagram of concentration according to scattered X-ray radiation energy for a X40CrMoV5-1 steel sample after cladding with laser, the laser beam power of 1.2 kW*

Laser treatment in the majority of cases increases the hardness of the tested steels and hardness is growing along with higher laser power used for alloying, as shown in Figures 39 and 40. Material hardness after alloying did not rise for titanium carbide only.

The tribological properties of steel are rising along with the growing surface layer hardness after laser alloying. Figs. 41 and 42 present the wear trace of the tested surface layers of hot-work alloy tool steels and Figs. 43 and 44 show the relative mass loss of the sample made of the tested steels according to the alloying material used and the laser power used for laser treatment.

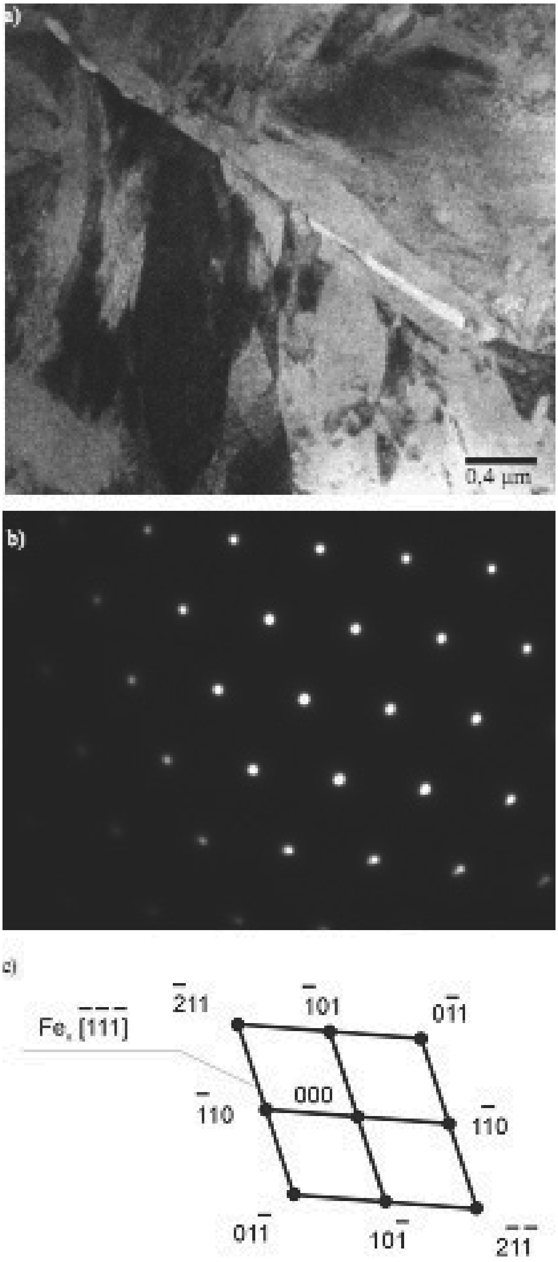


Figure 37. *Structure of thin foil made of 32CrMoV12-28 steel after alloying with VC vanadium carbide with the following parameters: scanning speed – 0.5 m/min, beam power – 2.0 kW, a) image in light field, b) diffraction pattern from the area as in figure a), c) diffraction pattern solution for figure b)*

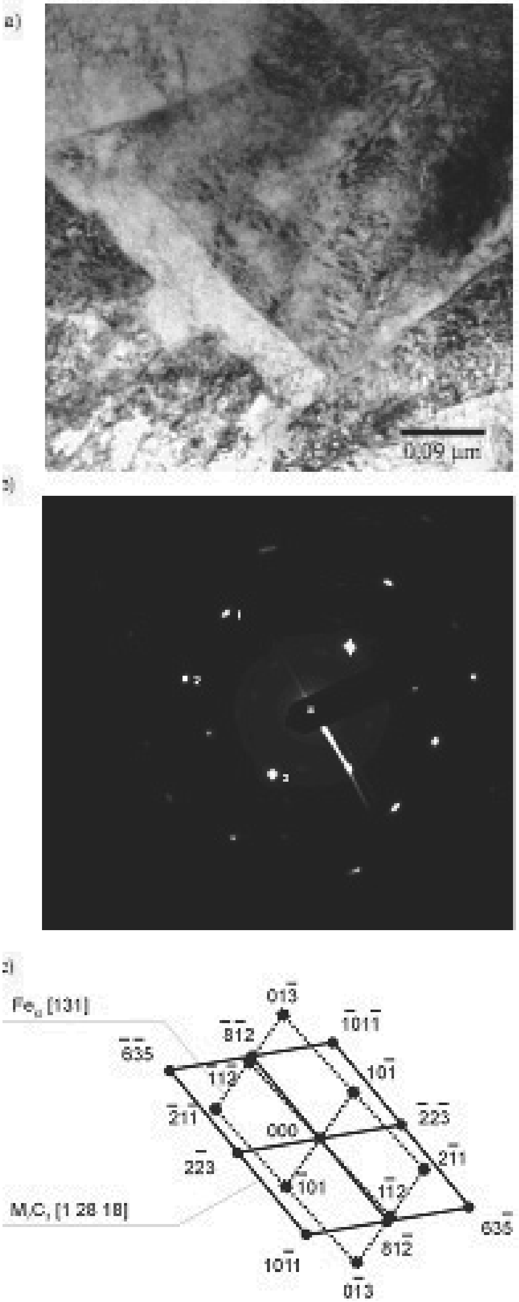


Figure 38. *Structure of thin foil made of X40CrMoV5-1 steel after alloying with NbC niobium carbide, laser beam power of 2.0 kW, a) image in light field, b) diffraction pattern from the area as in figure a), c) diffraction pattern solution for figure b)*

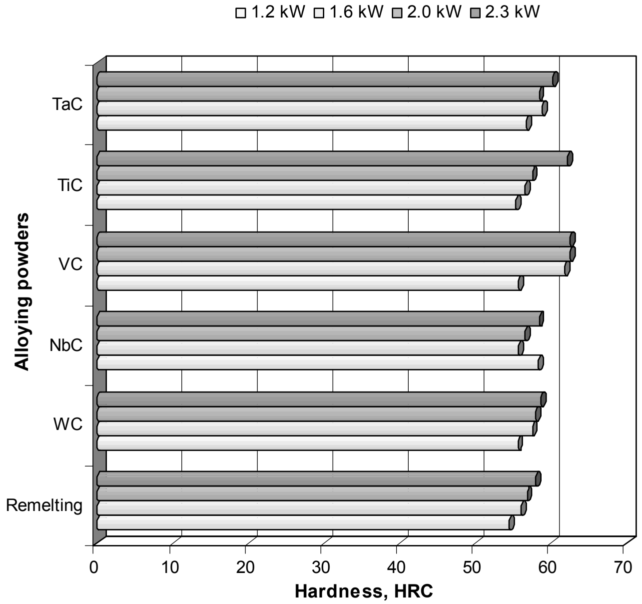


Figure 39. *Variation in surface layer hardness of X40CrMoV5-1 steel remelted or alloyed with the laser power range of 1.2-2.3 kW*

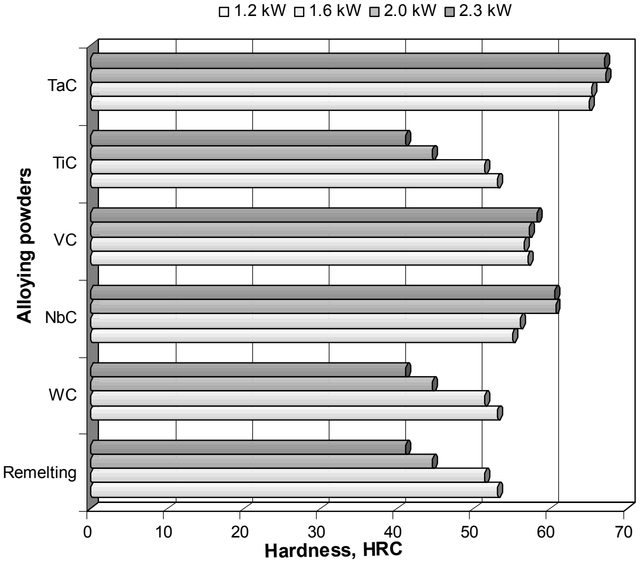


Figure 40. *Variation in surface layer hardness of 32CrMoV12-28 steel remelted or alloyed with the laser power range of 1.2-2.3 kW*

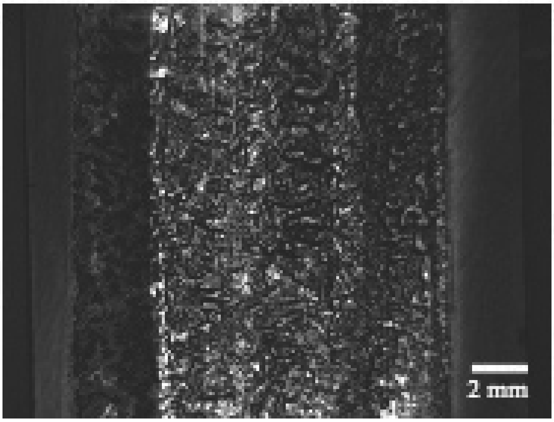


Figure 41. *Wear trace of the surface layer after an abrasion test acc. to ASTM G65 for X40CrMoV5-1 steel alloyed with WC tungsten powder, the laser power of 1.2 kW*

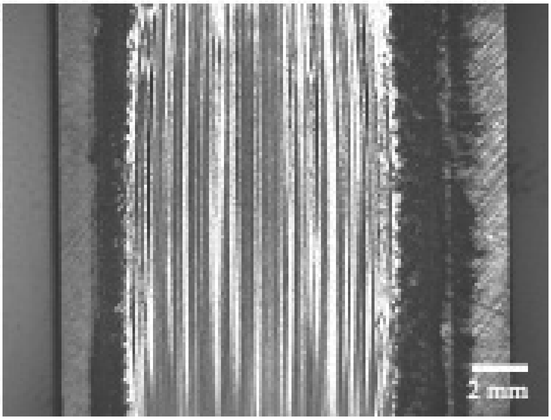


Figure 42. *Wear trace of the surface layer after an abrasion test acc. to ASTM G65 for 32CrMoV12-28 steel alloyed with TiC titanium powder, the laser power of 2.0 kW*

5. Technology roadmaps prepared for laser treated hot-work steels

On the basis of achieved results of experimental-comparative research a series of roadmaps of the analysed groups of technology were created. A representative technology roadmap prepared for the laser treatment of hot-work alloy tool steels using NbC niobium carbide powders in Table 7 is shown. The heading of the technology roadmap contains a basic

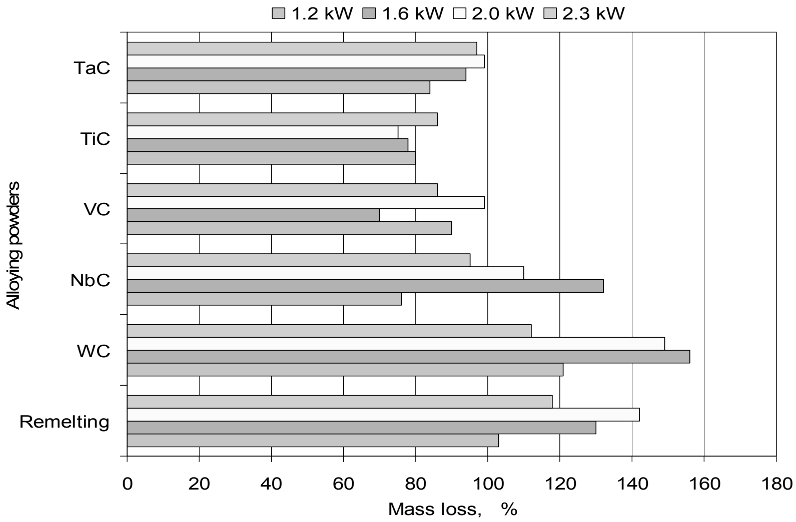


Figure 43. *The relative mass loss measured when testing wear resistance for X40CrMoV5-1 steel (100% – the mass loss of the heat-treated sample, not subjected to laser cladding or alloying with carbide powders)*

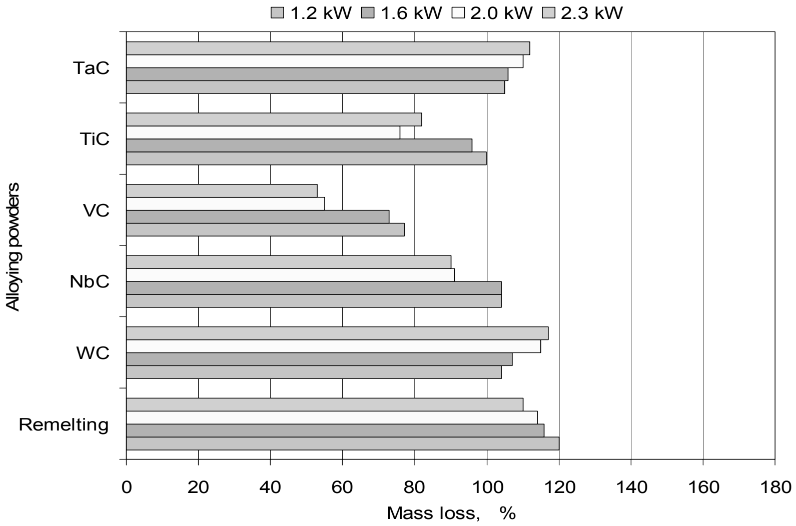
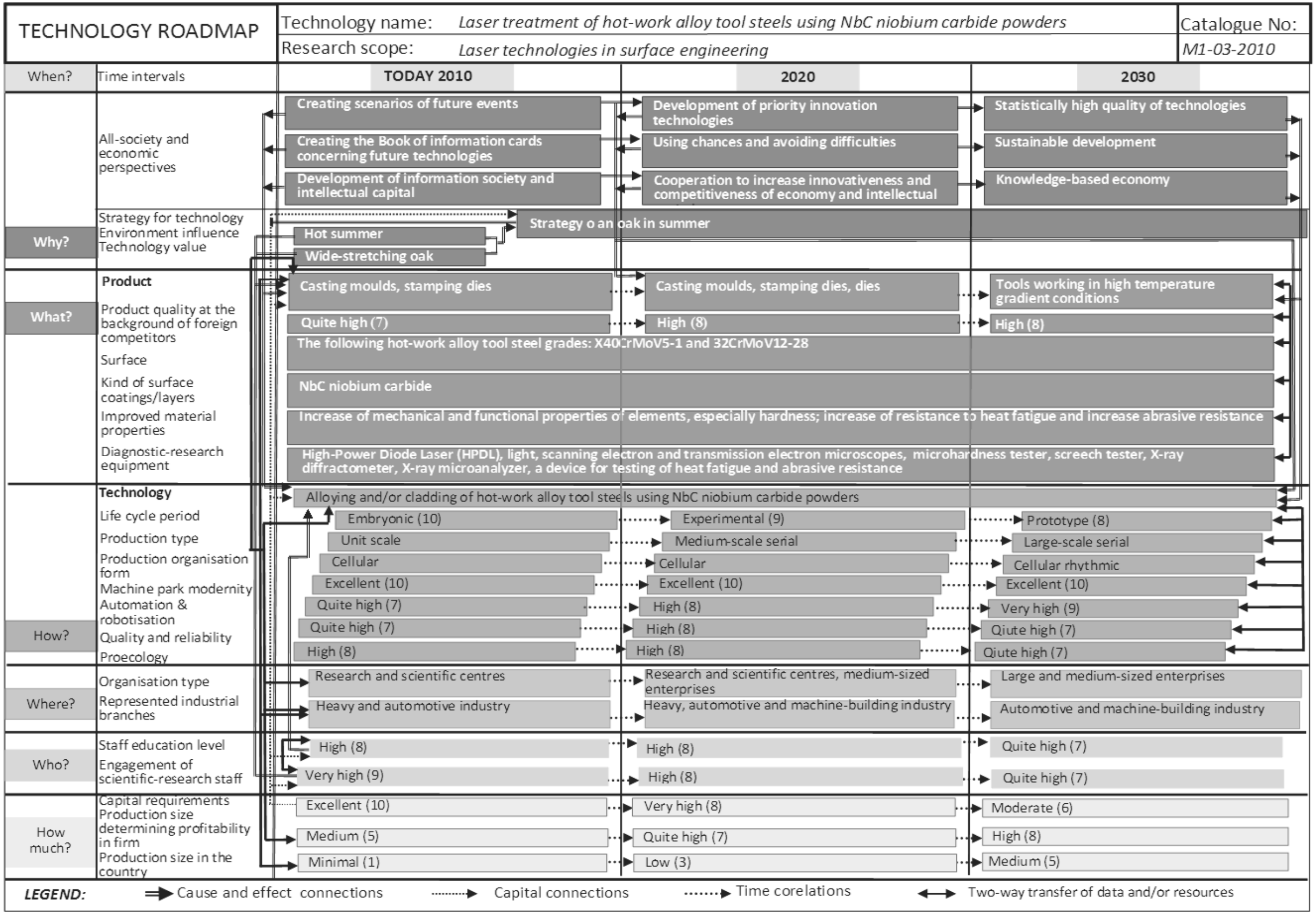


Figure 44. *The relative mass loss measured when testing wear resistance for 32CrMoV12-28 steel (100% – the mass loss of the heat-treated sample, not subjected to laser cladding or alloying with carbide powders)*

***Table** 7. Demonstrating technology roadmap for the laser treatment of hot-work alloy tool steels using NbC niobium carbide powders*



TECHNOLOGY ROADMAP		Technology name: *Laser treatment of hot-work alloy tool steels using NbC niobium carbide powders* Research scope: *Laser technologies in surface engineering*		Catalogue No: *M1-03-2010*
When?	Time intervals	**TODAY 2010**	**2020**	**2030**
	All-society and economic perspectives	Creating scenarios of future events	Development of priority innovation technologies	Statistically high quality of technologies
		Creating the Book of information cards concerning future technologies	Using chances and avoiding difficulties	Sustainable development
		Development of information society and intellectual capital	Cooperation to increase innovativeness and competitiveness of economy and intellectual	Knowledge-based economy
Why?	Strategy for technology	Strategy o an oak in summer		
	Environment influence	Hot summer		
	Technology value	Wide-stretching oak		
What?	**Product**	Casting moulds, stamping dies	Casting moulds, stamping dies, dies	Tools working in high temperature gradient conditions
	Product quality at the background of foreign competitors	Quite high (7)	High (8)	High (8)
	Surface	The following hot-work alloy tool steel grades: X40CrMoV5-1 and 32CrMoV12-28		
	Kind of surface coatings/layers	NbC niobium carbide		
	Improved material properties	Increase of mechanical and functional properties of elements, especially hardness; increase of resistance to heat fatigue and increase abrasive resistance		
	Diagnostic-research equipment	High-Power Diode Laser (HPDL), light, scanning electron and transmission electron microscopes, microhardness tester, screech tester, X-ray diffractometer, X-ray microanalyzer, a device for testing of heat fatigue and abrasive resistance		
How?	**Technology**	Alloying and/or cladding of hot-work alloy tool steels using NbC niobium carbide powders		
	Life cycle period	Embryonic (10)	Experimental (9)	Prototype (8)
	Production type	Unit scale	Medium-scale serial	Large-scale serial
	Production organisation form	Cellular	Cellular	Cellular rhythmic
	Machine park modernity	Excellent (10)	Excellent (10)	Excellent (10)
	Automation & robotisation	Quite high (7)	High (8)	Very high (9)
	Quality and reliability	Quite high (7)	High (8)	Qiute high (7)
	Proecology	High (8)	High (8)	Qiute high (7)
Where?	Organisation type	Research and scientific centres	Research and scientific centres, medium-sized enterprises	Large and medium-sized enterprises
	Represented industrial branches	Heavy and automotive industry	Heavy, automotive and machine-building industry	Automotive and machine-building industry
Who?	Staff education level	High (8)	High (8)	Quite high (7)
	Engagement of scientific-research staff	Very high (9)	High (8)	Quite high (7)
How much?	Capital requirements	Excellent (10)	Very high (8)	Moderate (6)
	Production size determining profitability in firm	Medium (5)	Quite high (7)	High (8)
	Production size in the country	Minimal (1)	Low (3)	Medium (5)

LEGEND: ⇒ Cause and effect connections ┈┈▶ Capital connections ┈┈▶ Time corelations ⟷ Two-way transfer of data and/or resources characteristic of the technology, including: the name of the technology, the represented research field and the given catalogue number. The horizontal axis of a roadmap corresponds to time intervals, and the vertical axis to seven layers called as following: time, conceptual, product, technological, spatial, staff and quantitative. This enables the setting, in one place, of data on the purpose, subject, manner, place, contractor and cost in relation to the analysed technology, taking into account the changes of these parameters in time. Upper layers placed in the top part of the technology roadmap, specifying general premises, causes and reasons of activity in the process of pulling, act on the fundamental middle layers pertaining to the product and technology. On the other hand, lower layers which specify the organisational-technical details act on the middle layers in an opposite direction, which is referred to in production management as pushing. Technology roadmaps are a very comfortable and practical tool of comparative analysis which facilitates the selection of technologies according to the selected criterion, and when supplemented by operation sheets with precise technological details – they enable the implementation of a given technology in industrial practice. A very large significance of technology roadmaps is their flexibility which enables their supplementing and expanding by new sub-layers depending on the arising needs. On the basis of data contained in given roadmaps prepared for all the analysed groups of laser treated hot-work alloy tool steels the summary presented in Table 8 was outworked.

Table 8. *Selected main source data used for preparation of roadmaps for laser treatment of hot-work steels using: (A) NbC niobium carbide, (B) TaC tantalum carbide, (C) TiC titanium carbide, (D) VC vanadium carbide and (E) WC tungsten carbide*

No.	Analysed factor	Time interval	Analysed technology				
			A	B	C	D	E
1.	Strategy for technology	2010	Strategy of an oak in summer	Strategy of an oak in summer	Strategy of an oak in spring	Strategy of an oak in spring	Strategy of an oak in autumn
		2020	Strategy of an oak in autumn	Strategy of an oak in autumn	Strategy of an oak in summer	Strategy of an oak in summer	Strategy of an oak in autumn
		2030	Strategy of an oak in autumn	Strategy of an oak in autumn	Strategy of an oak in spring	Strategy of an oak in spring	Strategy of an oak in autumn
2.	Environment influence	2010	Hot summer	Hot summer	Sunny spring	Sunny spring	Rainy autumn
3.	Technology value	2010	Wide-stretching oak	Wide-stretching oak	Wide-stretching oak	Wide-stretching oak	Wide-stretching oak

No.	Analysed factor	Time interval	Analysed technology				
			A	B	C	D	E
4.	Product	2010	Casting moulds, stamping dies	Blanking dies, stamping dies, dies	Forgings, dies, casting moulds	Dies	Stamping dies, forgings, dies
		2020	Casting moulds, stamping dies, dies	Blanking dies, stamping dies, dies	Plastic forming dies, punches, stamping dies	Dies	Stamping dies, forgings, dies
		2030	Tools working in high temperature gradient conditions	Stamping dies with long periods of use	Construction elements, biomaterials using other substrate materials	Dies, casting moulds	Stamping dies, forgings, dies
5.	Product quality at the background of foreign competitors	2010	Quite high (7)	High (8)	Moderate (6)	Moderate (6)	Moderate (6)
		2020	High (8)	High (8)	High (8)	High (8)	Quite high (7)
		2030	High (8)	High (8)	High (8)	High (8)	High (8)
6.	Improved material properties	2010-2030	Increase of mechanical and functional properties of elements, especially hardness; increase of resistance to heat fatigue and increase abrasive resistance				
7.	Diagnostic-research equipment	2010-2030	High-Power Diode Laser (HPDL), light, scanning electron and transmission electron microscopes, hardness tester, microhardness tester, screech tester, X-ray diffractometer, X-ray microanalyzer, a device for testing of heat fatigue and abrasive resistance, profilometer, potentiostat				
8.	Life cycle period	2010	Embryonic (10)	Embryonic (10)	Embryonic (10)	Embryonic (10)	Embryonic (10)
		2020	Experimental (9)	Experimental (9)	Experimental (9)	Prototype (8)	Prototype (8)
		2030	Prototype (8)	Growth (7)	Early mature (6)	Early mature (6)	Mature (5)
9.	Production type	2010	Unit scale	Unit scale	Unit scale	Unit scale	Unit scale
		2020	Medium-scale serial	Medium-scale serial	Small-scale serial	Medium-scale serial	Small-scale serial
		2030	Large-scale serial	Large-scale serial	Small-scale serial	Medium-scale serial	Large-scale serial
10.	Production organisation form	2010	Cellular	Cellular non-rhythmic	Cellar	Cellular	Cellular
		2020	Cellular	Cellular non-rhythmic	Cellular	Cellular non-rhythmic	Cellular
		2030	Cellular non-rhythmic	Cellular non-rhythmic	Cellular non-rhythmic	Cellular non-rhythmic	Cellular rhythmic

No.	Analysed factor	Time interval	Analysed technology				
			A	B	C	D	E
11.	Automation and robotisation	2010	Quite high (7)	Quite high (7)	Quite high (7)	Quite high (7)	Quite high (7)
		2020	High (8)	Very high (9)	High (8)	High (8)	High (8)
		2030	Very high (9)	Very high (9)	Excellent (10)	Very high (9)	Excellent (10)
12.	Quality and reliability	2010	Quite high (7)	Quite high (7)	Medium (5)	Medium (5)	Medium (5)
		2020	High (8)	Quite high (7)	Moderate (6)	Quite high (7)	Quite high (7)
		2030	Quite high (7)	Quite high (7)	High (8)	High (8)	Very high (9)
13.	Proecology	2010	High (8)	High (8)	Very high (9)	High (8)	High (8)
		2020	High (8)	Quite high (7)	Very high (9)	High (8)	High (8)
		2030	Quite high (7)	Quite high (7)	Very high (9)	High (8)	High (8)
14.	Organisation type	2010	Large and medium-sized enterprises, research and scientific centres, technological parks				
		2020	Large and medium-sized enterprises, research and scientific centres, technological parks				
		2030	Small and medium-sized enterprises, research and scientific centres, technological parks				
15.	Represented industrial branches	2010	Heavy and automotive industry	Heavy and automotive industry	Tool and heavy industry	Automotive industry	Tool and automotive industry
		2020	Heavy, automotive and machine-building industry	Automotive and machine-building industry	Automotive and light industry	Automotive industry	Tool and automotive industry
		2030	Automotive and machine-building industry	Automotive and machine-building industry	Tool, automotive, shipbuilding and biomedical industry	Automotive industry, fine mechanics elements	Automotive industry
16.	Staff education level	2010	High (8)	High (8)	Very high (9)	High (8)	High (8)
		2020	High (8)	High (8)	Quite high (7)	Quite high (7)	Quite high (7)
		2030	Quite high (7)	Moderate (6)	Quite low (4)	Medium (5)	Low (3)

No.	Analysed factor	Time interval	Analysed technology				
			A	B	C	D	E
17.	Engagement of scientific-research staff	2010	Very high (9)	Very high (9)	Very high (9)	Very high (9)	Very high (9)
		2020	High (8)	High (8)	High (8)	Moderate (6)	Medium (5)
		2030	Quite high (7)	Quite high (7)	Medium (5)	Quite low (4)	Quite low (4)
18.	Capital requirements	2010	Very high (9)	Very high (9)	High (8)	Quite high (7)	Medium (5)
		2020	Very high (9)	Very high (9)	Moderate (6)	Medium (5)	Quite low (4)
		2030	Excellent (10)	High (8)	Quite low (4)	Low (3)	Quite low (4)

6. Conclusions

The chapter presents the results of the interdisciplinary experimental-comparative research conducted mostly at the interface of material surface engineering and technology foresight. The purpose of the research was to determine the value of laser treatment of hot-work alloy tool steels compared to other technologies and to identify the recommended strategies and strategic development tracks for these technologies, taking into account the impact of such treatment on hardness, abrasion resistance and coarseness. The presented results of materials science research demonstrate a promising improvement of the functional properties of the tested materials. The melted zone (RZ), the heat-affected zone (HAZ), and the transition zone (TZ) were found in the surface layer; it was also found that laser cladding and/or alloying with carbide powders influences the refinement of the structure for both steel grades within the entire tested laser power range (1.2-2.3 kW). It was also concluded that the ceramic powders of oxides and nitrides do not melt into the tested steel's surface layer during alloying. A fine-crystalline, dendritic structure with the crystallisation direction connected with the dynamic evacuation of heat from the laser beam-affected zone occurs in the melted zone and/or alloyed zone. A high-quality surface layer with no cracks and defects and with its hardness much higher than the substrate material can be produced as a result of the heat treatment and laser cladding and/or alloying of X40CrMoV5-1 and 32CrMoV12-28 tool steel with ceramic powders using a high power laser. The properties of the tested steel and of the structural mechanisms occurring when producing the surface layers can be also thoroughly identified with the testes performed. The laser alloying of the tested steel with ceramic particles complicates, however, predictions as to how the material will behave in use. A very complex system, much more complicated than for hot-work steel unremelted with ceramic powders only, is created as the interaction of stress fields is overlapping with dislocation movements and the presence of microcracks. Improved resistance to abrasive wear and mechanical and tribological properties exhibited by the materials are achievable in particular through alloying with titanium carbide and vanadium carbide particles. Decisive for the further functional properties of the ready product is not only the appropriate selection of the ceramic powder used for alloying, but also its arrangement and volume fraction in the matrix modelled with different process operations. Clear growth in roughness and a higher bead face irregularity are seen when heightening laser power. The phenomenon is linked to the higher absorption of laser radiation by the sample surface. Higher energy absorption is also intensifying the process of cladding the steel surface layer. The heat fatigue resistance tests performed have a major effect on selecting the right ceramic powder for alloying hot-work steel, enabling to categorise the powders used according to their suitability for this type of laser treatment. To sum up one can conclude that titanium carbide TiC and vanadium carbide VC powders are most useful powders considering the improved heat fatigue resistance of both laser-alloyed steel grades. On the other hand, resistance is smaller if tantalum carbide and niobium carbide powders are used that produce alloyed surface layers with very high hardness and resistance to abrasive wear. The tests carried out point out that it is reasonable to use and apply in practise the technology of alloying X40CrMoV5-1 and 32CrMoV12-28 hot-work alloy tool steels grade using a high power diode laser. The final action closing the experimental-comparative works was to create a series of technology roadmaps of the analysed technology groups. The creation and use of this tool allows for presenting, in a uniform and clear format, various types of factors which directly and indirectly characterize given groups of technologies together with the forecast and perspectives of their development during the next twenty years.

A distinguishing characteristic of foresight research is that it looks, often very far, into the future. Therefore, it is reasonable to conclude by indicating the most state-of-the-art and highly promising directions of research which is currently conducted by the Institute of Engineering Materials and Biomaterials of the Silesian University of Technology. The research includes an effort to solve the problem of making a hybrid connection of the technology of sintering and convection cooling, with additional laser treatment, in order to produce sintered steels which are corrosion resistant and have surfaces without any porosity and characterised by improved corrosion resistance and mechanical properties [49]. This modern direction of studies is aimed at producing sintered stainless steel with its surface free of any roughness and offering higher corrosive resistance and mechanical properties. The final outcome of the proposed technology is to achieve a duplex structure in the surface layer on the substrate made of sintered ferritic single-phase steel and austenitic steel that will be characterised by improved anticorrosive properties, in particular improved resistance to pitting corrosion and a duplex structure with enhanced mechanical properties on the substrate made of sintered dual-phase steel characterised by improved corrosive resistance combined with strong grain refining resulting from fast crystallisation, which will additionally improve functional properties. In addition, the modern surface treatment methods combined with the controlled depth of laser beam's interaction and introducing additional alloying materials into the surface layer allows to achieve a gradient structure of the item, which is beneficial considering functional properties. Other state-of-the-art and promising works contain the effect of specific elements introduced into TRIP steel on its structure and properties is also undertaken. Complex hot-work tool steels should be characterised by their functional properties first of all (such as abrasive resistance and resistance to heat fatigue) exceeding other steel grades. Of note are also studies over hot-work tool steel properties are concerned with the impact of micro-additions, especially Ce, Zr and Ti on the progress of structural mechanisms and the properties of thermally-treated steel, with subsequent heat fatigue due to repetitive inductive heating and fast cooling. Studies have also been undertaken on the enrichment of surface of such steel by applying other types of lasers, including disc lasers.

Summing up, it should be underlined that the foresight- materials science research described in this chapter are a fragment of broader individual activity [1-3, 37-43, 50-53] aimed at selecting, researching, characterizing and determining strategic development perspectives of priority innovative material surface engineering technologies in the process of technological e-foresight understanding as computer aided scientific forecasting and shaping of the future in researched area.

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