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Development of wire based laser alloying process for highly stressed surfaces of hot forming steel tools

Konstantin Hofmann[a], Steffen Schmitt[a], Matthias Holzer[a], Vincent Mann[a], Florian Hugger[a], Stephan Roth[a,c], Michael Schmidt[a,b,c]

[a] *blz – Bayerisches Laserzentrum GmbH, Konrad-Zuse-Str. 2-6, 91052 Erlangen, Germany*
[b] *Institute of Photonic Technologies, Universität Erlangen-Nuremberg, Konrad-Zuse-Str. 3/5, 91052 Erlangen, Germany*
[c] *SAOT – Erlangen graduate school in advanced optical technologies, Paul-Gordan-Str. 6, 91052 Erlangen, Germany*

Abstract

The machining of high strength steels for vehicle parts in press hardening processes requires high process temperatures which lead to high tool stresses with huge wear. In order to reduce mechanical wear, a local laser alloying process is developed to increase tool-endurance. Therefore, filler material in form of a compact filler wire is used which ensures higher material utilization as well as an avoidance of decomposition problems in comparison to powder based alloying processes. Moreover a dynamic laser beam deflection is necessary to enable a turbulent flow of melt for a homogeneous distribution of alloying elements. To ensure homogeneous dispersion of the alloying elements in the alloying area as well as uniform mechanical properties of the surface, a process development for wire based alloying processes, like different parameters with oscillating laser beam and compositions of alloying elements is necessary.
The development of different beam oscillation frequencies in combination with various wire feed velocities enables a suitable process for an adaption of the surface properties. To reach the material-specific element concentrations for hot forming tool steels, which typically lead to an improvement of mechanical and thermo-mechanical properties and increase the wear resistance, the base material is alloyed with nickel and chromium. Oscillation frequencies between 50 and 400 Hz and oscillation amplitudes of the double wire diameter enable the reentry of the oscillating laser beam into still existing melt pools and a stable alloying process.

Keywords: Laser beam alloying, filler wire material, hot forming steels, adhesive and abrasiv wear, Macro Processing: Surface Treatment and Cladding

1. Introduction / Motivation

The requirements on vehicle safety in automotive engineering, at simultaneous realization of light weight constructions, demand the usage of high strength steels. Press hardening processes enable the simultaneous forming and hardening of boron-manganese-steels with a resulting mechanical strength of more than 1,000 MPa. Because of high material temperatures during heating, the steel blanks have to be shielded against scaling. Therefore mostly Al-Si-coatings are used, which tend to adhesive residua on the tool surfaces and induce some degradation of functional surfaces of press hardening tools. Next to adhesive residua also abrasive wear, induced by high process forces, decreases tool quality. In order to countervail this disadvantage, a local modification of high stressed tool surfaces is used to avoid mechanical wear and increase the mechanical properties. Because of higher material usage and to avoid material decomposition at comparable powder based alloying processes, wire-based filler material is used. In order to ensure homogeneous distribution of alloying elements and thus uniform material properties, a turbulent melt stream is necessary [1]. Therefore different scanner based beam deflection frequencies are investigated. To ensure a homogeneous melt flow from the wire end into the melt bath the positioning of the wire has to be considered. Different oscillation frequencies and filler wires with varying compositions are used whereof the resulting metallurgical structure formation in the alloying lines is analyzed. Furthermore the necessary and possible melting of very small amounts of filler materials as well as the influence of different alloying spot diameters towards the resulting melting depth have to be analyzed. For the development of the alloying process, the filler wires are positioned in a static state on the tool surface to investigate the possibilities towards metallurgical and mechanical property modification, which is done by hardness measurement and element analysis.

1.1. State of the art

Laser beam alloying and -dispersing are suitable processes for a local material modification to increase the endurance of hot forming tool steels in press hardening processes. A local melting of the tool surface and a simultaneously input of alloying elements allow the generation of a structure with adapted properties like a high mechanical strength [2]. In comparison to laser beam hardening, also properties like warm- and creep strength, hardenability as well as resistance against wear and scale can be improved. Furthermore the structure can be modified towards ductile or brittle material properties in order to reach a combination of both characteristics at one press hardening tool but at different areas [3]. Powder based laser alloying processes can be performed in a single-stage with a simultaneous powder feed, see Figure 1a, or in a double-stage with an upstream powder fill [2]. The powder input at the single-stage process is performed in process either with pure elements (e.g. W, Mo, V, Mn, or Cr) or with metal carbide like tungsten carbide for improvement of hot wear resistance [4], [5]. In the double-stage process the alloying powder is prepositioned by a squeegee and then downstream fused with the base material. Both the single-stage as well as the double-stage process have to encompass a homogeneous distribution of the alloying elements, which can be induced by a dynamic beam oscillation in order to provoke a turbulent melt flow, see Figure 1b [2].

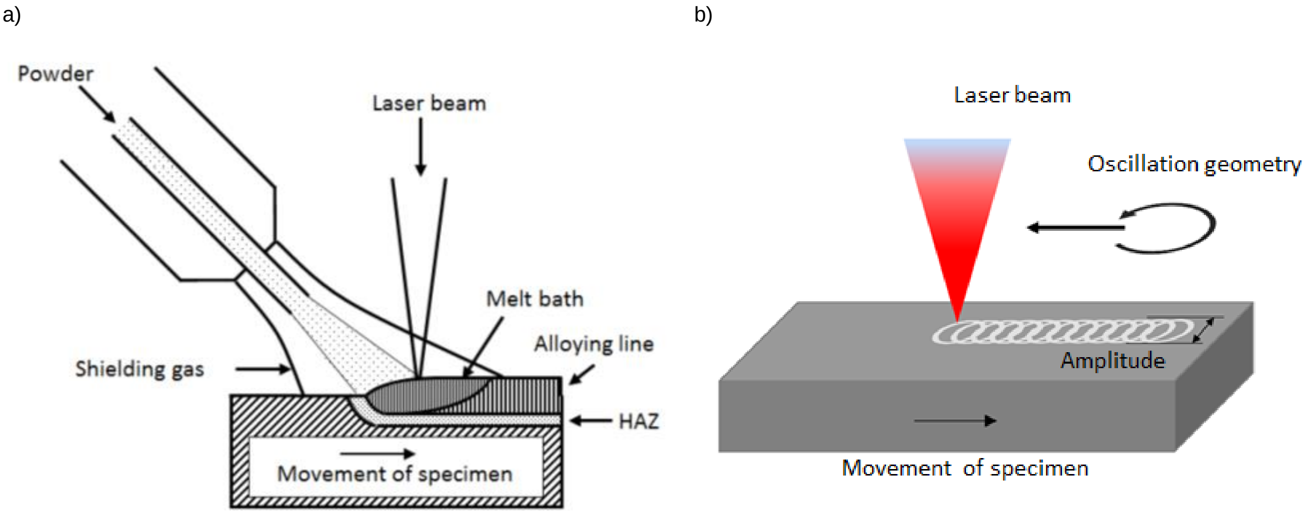

Figure 1: Schematic illustration of a) powder-based laser alloying process and b) laser beam oscillation, according to [2]

For the improvement of mechanical properties by laser beam alloying, the chemical element chromium increases the wear and scaling resistance of hot forming steels especially at high temperatures [6]. Furthermore the alloying elements tungsten, vanadium and molybdenum induce a higher resistance against hot wear as well as an improved temperature change and tempering resistance of the structure [7]. Alloying elements like molybdenum, chromium and vanadium are used to meet the requirements of high temperature strength, thermal shock resistance as well as a high resistance against warm wear in tools with a high mechanical strain. In laser alloying processes of case hardening steels, especially the carbon concentration in the edge layer influences wear resistance. Based on the increasing lattice distorsions into tetragonal martensite, an increase of hardness especially at carbon concentrations up to 0.8 wt.% can be achieved. Aditionally carbon forms charbides in combination with chromium and vanadium which is relevant for a secondary hardness maximum. However at increased carbon concentrations (C > 0.8 wt.%), the retained austenite fraction increases which leads to a decrease of hardness and increase of ductility [6], [8]. Depending on the carbon-concentration as well as the concentration of alloying elements, the martensite start temperature can be calculated according to formula 1 as well as the martensite finish temperature which results out of the decuction of M_S – 215°C. According to Steven and Haynes the marteniste finish temperature is reached after passing the temperature intervall of 215°C ± 15°C which is deduced from the calculated martensite start temperature in dependance of the alloying element contents. In order to maximize the microhardness, the amount of martenistic micro structure has to be enlarged, which requires to minimize the content of residual austenite at the attainment of room temperature. To avoid high ammouts of retained austenite, the influences of the alloying elements on the martensite start as well as the martensite finish temperature has to be considered during the determination of the target element concentrations. Furthermore the specific target concentration values for hot forming steels like 1.3 wt.% nickel as well as 13 wt.% chromium are the limiting concentration to enable an increase of hardness and scale [6].

$$M_S = 764.2 – 302.6*wt.\% C – 30.6*wt.\% Mn – 16.6*wt.\% Ni – 2.4*wt.\% Mo – 1.3*wt.\%Cu+8.58*wt.\%Co+7.4*wt.\%W-14.5*wt.\%Si [°C]; (1) [9]$$

In order to induce a specific metallurgic structure formation, the chemical composition in the alloyed lines can be influenced by procedural parameters like variation of feeding rate of filler material and base material [11]. Thereby the ability to microstructural transformation towards martensitic structure in the alloyed lines depends on the alloyed concentration and becomes inertial with rising martensite start temperature.

The disadvantages of powder based laser alloying processes, like the inhomogeneous structure formation, based on a demixing of powder compositions with different densities, provoke the need of a process development, which avoid these detriments [12]. Therefore a wire based laser alloying process in combination with a spatial beam deflection appears as appropriate methode to achieve the requirements. In order to ensure a homogeneous input of alloying material into the structure, continuous melting rates have to be ensured for a constant intermixture of alloying elements and base material. Next to the homogeneous melt flow, also the reentry of the oscillating laser beam into the alloying line has to be observed in order to ensure a still existing melt bath. To enable a homogeneous distribution of elements in the alloyed line, a developement of a local beam oscillation is performed [13]. To investigate the process boundaries, oscillation geometries, -frequencies and –amplitudes as well as resulting wire feed rate have to be investigated. Next to the process limits using beam oscillation, also the effect of changing laser beam power density on the resulting alloying depth are investigated. In detail, the melting volume of the base material in dependance on the energy input per unit length have to be apprised as basic information for the subsequent choice of filler material and their resulting meltdown volume.

1.2. Experimental setup

For the experimental investigation of the wire based laser alloying process, a fiber laser IPG YLS-1000 with a maximal power of 1 kW is used in combination with a 2D-scanner optic raylase superscan with a f-theta lens and focal length of 154 mm. Beam oscillation of up to 1 kHz can be achieved. The galvanometric controlled mirrors in the scanner generate circular beam oscillations. The specimens are handled on an x-y-axis with an adjustable movement speed between 1 – 14 mm/sec. Two different filler wires are used for the alloying processes and are positioned on the tool surface as well as fed by a wire feeder DIX FDE-PB 100L supplied by Dinse, which is modified to fulfill the requirements of low feeding rates. The experimental setup is illustrated in Figure 2.

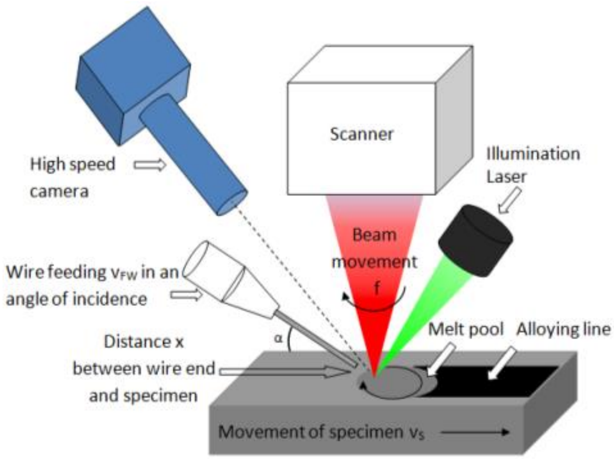

Figure 2: Schematic view of the experimental setup

Two different nickel and chromium containing filler wires are used with diameters of 0.8 mm and 1.2 mm. Depending on the concentration of alloying elements in base material and filler wires, the necessary wire feed rate is calculated in order to reach the specific concentration for improving the hardness. Experimental investigations showed a minimal feasible wire feed rate of 4.1 mm/sec, because smaller feeding velocities induce some inhomogeneous filler material supply, which leads to an interruption of the continuous element input. By knowing the process boundaries for constant wire feeding, the necessary cross section of the molten base material can be calculated to reach the target concentration (such as Ni: 1.3 wt.%) for specific alloying elements. The selection of filler materials 1.4430 and 1.4316 was made because of the nickel content which tends to reach the target concentration of 1.3 wt.% in combination with the molten base material at a stationary positioned filler material during the alloying process on the tool surface as well as molybdenum which increases high temperature stability and thermal shock resistance [6]. The chemical compositions of base materials and filler wires, as well as the laser parameters are shown in Table 1.

Table 1: Data of used raw material, filler material, laser source and alloying parameter

Base material and filler wire		Cr [wt.%]	Mo [wt.%]	V [wt.%]	Ni [wt.%]	Mn [wt.%]	C [wt.%]
BM	1.2379	12	0.8	0.9	-	-	1.55
	WP7V	7.8	1.5	1.5	-	-	0.5
FW	1.4316	20	-	-	10	1.7	0.02
	1.4430	18	3.5	-	12	1.8	0.03

Physical value	Figure
Laser power P_L (max.) [W]	1000
Wavelength λ [nm]	1070
Spot diameter d_F [µm]	34
Oscillation frequency f [Hz]	25-400
Amplitude b [mm]	1.6-3.2
Wire feeding velocity v_{FW} [mm/s]	4.1-10
Diameter of filler material d_{FM} [mm]	0.8 and 1.2
Specimen feeding velocity v_S [mm/sec]	1-14

Furthermore, high-speed-imaging at a maximum frame rate of 37,000 fps with a resolution of 512 x 512 was performed to observe the melting of the filler wire and the continuous flow of molten material into the melt pool. For the analysis of the alloyed lines, microsections have been prepared to measure width and depth as well as the microhardness and the distribution of the alloying elements. The investigation of the alloy element concentrations is done with micro X-ray fluorescence analysis to measure their local concentration in the melting zone.

2. Results and Discussion

Within the experimental investigations, two different filler wires with a diameter of 0.8 mm and 1.2 mm are used to develop the wire based laser beam alloying process for the local surface modification of hot forming tools steels WP7V and 1.2379. Both different laser beam oscillation frequencies between 25 Hz and 400 Hz as well as various common boundaries of the fire feed tip concerning the angle of incidence between 0° - 45° and the distance between the loose wire end and the specimen surface are investigated. In detail, the dependency of different oscillation frequencies at specific specimen feeding velocities concerning the resulting alloying depth are investigated at fixed filler wire feeding speeds. The results of the investigated angles of incidence between 0° and 45° with increments of 5° show, that the wire feed tip has to be engaged in an angle of incidence below 35° to the specimen surface. Especially at angles of incidence higher than 35°, a local inhomogeneous melting of the wire end arises, which leads to process instabilities with irregular melt flow. Furthermore, the gap between the wire end and the tool surface should not exceed a minimal required distance of 0.2 mm to provide the necessary amount of filler material, especially at the beginning of the alloying process. Especially at higher gaps, the distance between the loose wire end and the melt bath is too high in order to bridge the distance, thus small wire feeding speeds of only 4.1 mm/sec are applied. The mentioned results are valid both for filler wires with a diameter of 0.8 mm and 1.2 mm, because no conspicuous difference can be observed.

The results of the investigated oscillation amplitude between 0.5 * d_{FM} and 2.5 * d_{FM} show, that an amplitude of 2 * d_{FM} is required to enable a homogeneous meltdown of filler material at a wire feeding speed of 4.1 mm/sec. With rising oscillation amplitudes > 2 * d_{FM}, the essential thermal energy for melting the filler material is not enough to enable a homogeneous material flow from the wire into the process zone. Additionally, at higher oscillation frequencies, the thermal energy input for the meltdown of filler material declines especially during the processing of the outline contours of the oscillation circle. Thereby the homogeneous meltdown of the wire end is interrupted, which leads to process instabilities like a self wetting, see Figure 3a.

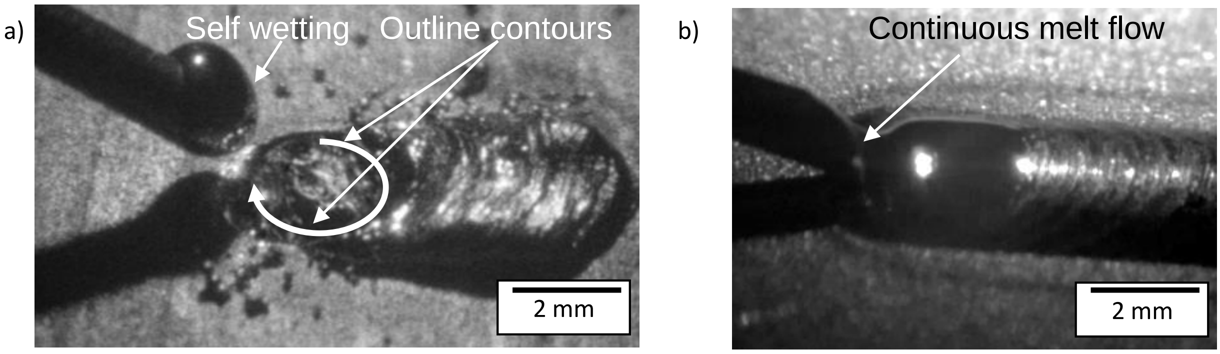

Figure 3: Images of a wire based laser alloying process observed with a high-speed-camera; P = 500 W; f = 400 Hz; v_{FW} = 10 mm/sec, v_s = 3 mm/sec, FW 1.4316 (Ø 0.8 mm); a) self-wetting at the loose wire end without contact to the melt pool at an amplitude of b = 2.0 mm; b) continuous meltdown of the filler wire into the melt bath at an amplitude of 1.6 mm

Next to the investigated process boundaries concerning the filler material input, the resulting alloying depth for feeding speed of the specimen between 1 mm/sec and 14 mm/sec is carved out. Thereby the maximum alloying depth is reached at an oscillation frequency of 25 Hz, see Figure 5, for each specimen feeding speed between 1 mm/sec and 8 mm/sec. Especially at higher feeding speeds, the resulting energy input per unit length declines and leads to decreasing melting depths. Nevertheless the resulting alloying depth at 25 Hz is not formed homogeneously because the local energy input during one circulation differs and reaches its maximum at the overlap due to the spatial beam movement, see Figure 4. This can be attributed to the circular oscillation, superposed with a feed motion of the specimen which leads to an overlap at the lateral boundary area.

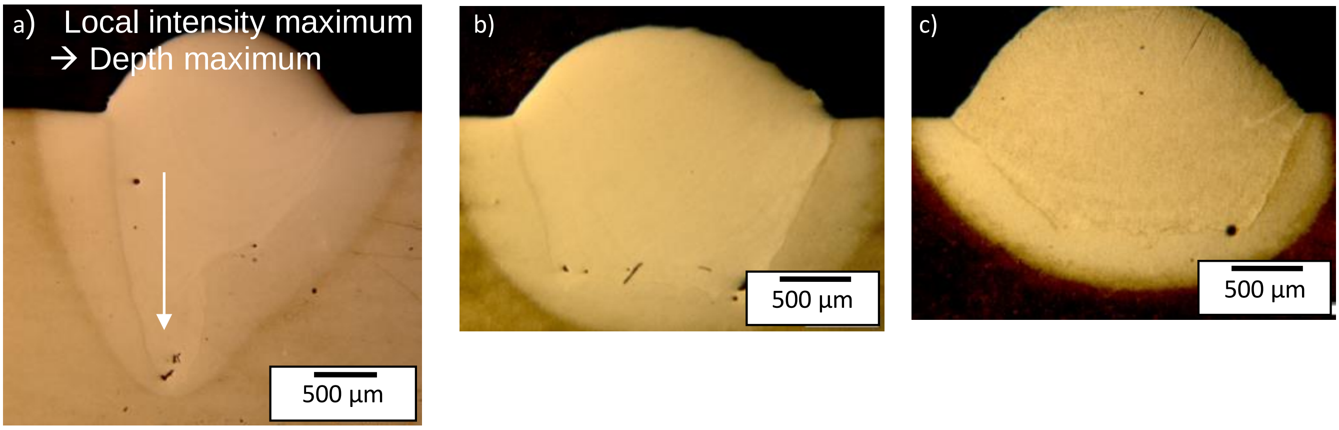

Figure 4: Cross section of alloying lines a) f = 25 Hz with an inhomogeneous melting depth and b) f = 150 Hz cylindrical shaped alloyed line; c) f = 350 Hz cylindrical shaped alloyed line; P = 500 W; v_{FW} = 10 mm/sec, v_s = 4 mm/sec, FW 1.4316 (Ø 0.8 mm)

At higher frequencies than 25 Hz, cylindrical shaped alloyed cross sections can be realized whereas the resulting melting depth declines because of a decreasing energy input per unit length, see Figure 4. At higher oscillation frequencies than 400 Hz at the given amplitudes, the effectively performed geometry differs from a typical circular shape and can not be fulfilled with the contour accuracy, because the boundary of the mechanical inertia of the mirrors in the scanner is reached for the used amplitude values.

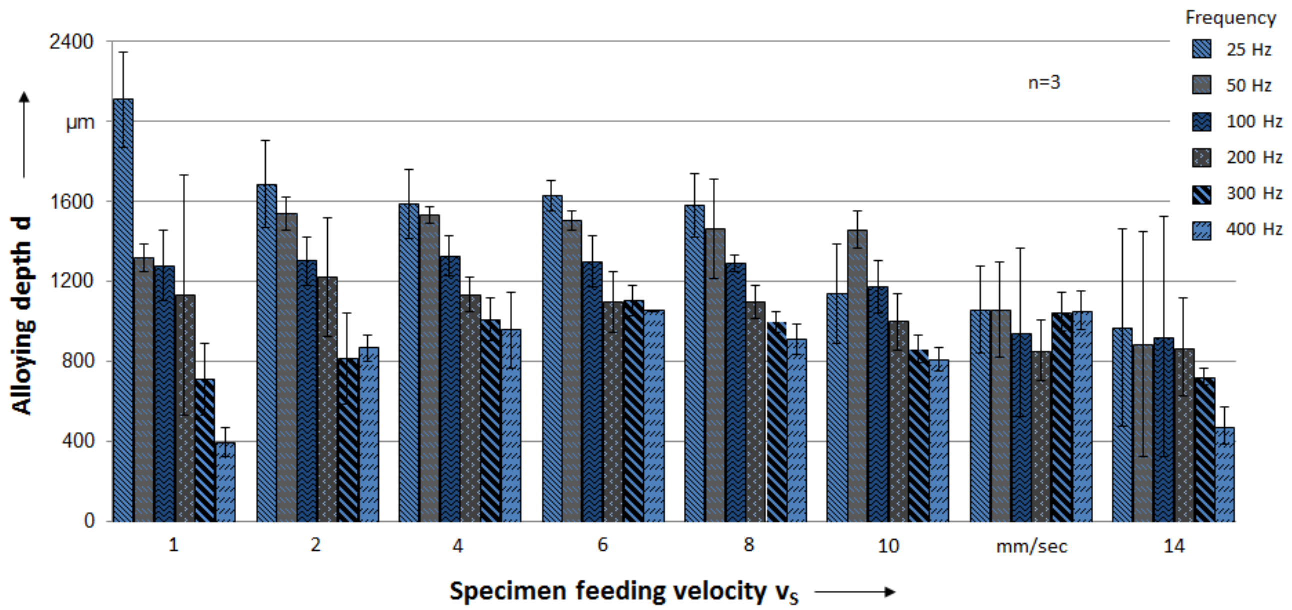

Figure 5: Alloying depth over axis speed at various oscillation frequencies; P_L = 500 W; v_{FW} = 8.3 mm/sec; b = 1.5 mm

With rising feeding speeds of the specimen in the alloying process, the melting depth declines because of a decreasing energy input per unit length. In detail the alloying depth both at 1 mm/s as well as feeding speeds higher than 8 mm/s limit the alloying process and form the operating range in order to fulfill the maximization of cylindrical shaped alloying depths. At 1 mm/sec feeding speed of the specimen, the volume of molten filler material is ten times higher at a constant feeding speed of the filler material, compared to 10 mm/sec feeding speed, because process time declines by the same factor. With increasing feeding speed of the specimen, the amount of insert filler material per unit length declines as well as the energy input per unit length, which induces a decrease the alloying depth. Especially for higher process velocities than 8 mm/sec, the resulting alloying depth does not fulfill typical alloying depths of press hardening tools and limits the process itself. Additionally the reinforcement of the alloyed lines declines with rising specimen feeding speeds from averaged 1400 µm at 1 mm/sec specimen feeding speed, whereat no frequency dependent difference is observed, to averaged 350 µm at 14 mm/sec feeding speed, because the volume of filler material per unit length declines. In general, the declining reinforcement of alloyed lines as well as decreasing width at rising specimen feeding speeds can be attributed to the declining volume of filler material, which is provided in the alloying process.

In order to investigate the resulting alloying depth for different laser spot diameters, an increase of the focal diameter is performed by an in-process defocussing, to check the influence of chancing tool surfaces, e.g. radiuses, towards the melting depth. Next to the movement of the specimen, a synchronized motion of the scanning system is superposed to check the influence of a total defocussing of 5 millimeter over an alloying line length of 20 millimeter. The resulting alloying depth, shown in a longitudinal section is plotted over the resulting spot diameter on the specimen surface as well as the value of defocusing under the usage of static positioned filler wires on the specimen surface, see Figure 6. During the alloying process on the flat tool surface, the alloying depth is performed homogeneous until a defocussing value of 3.4 mm with a resulting spot diameter of 280 µm. This represents the process boundary at changing machining planes, whereat the alloying depth can still be ensured. At further defocussing, the amount of molten base material decreases because of a declining laser intensity. Furthermore, the increasing ratio between the amount of molten base material and filler material can be confirmed by means of the concentration change in the alloyed line especially at a defocussing value of 5 millimeter. Finally, a continuous decrease of the molten base material can be observed.

The defocussing value of 3.0 millimeter, respectively 280 µm focal diameter represents the point of inflection because the alloying depth declines. At higher values of defocussing, the focus position has to be retraced to ensure the melting depth and thus to achieve the desired element concentration.

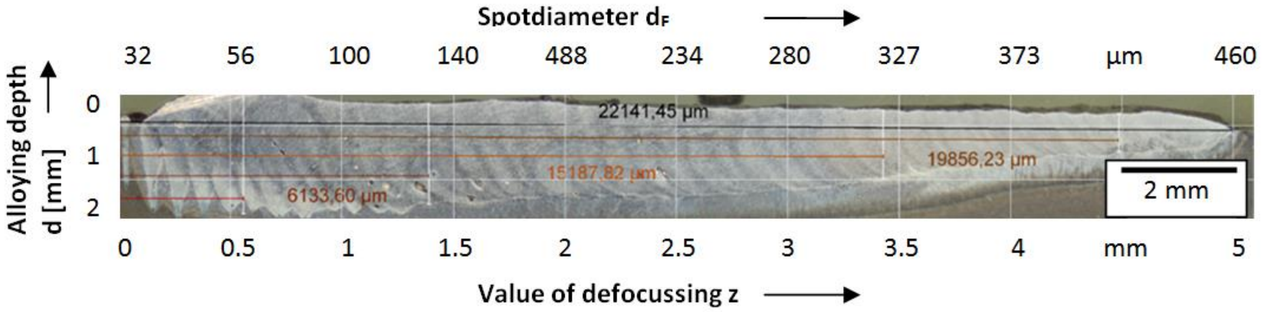

Figure 6: Alloying depth during an in-process defocusing; P_L = 500 W, f = 50 Hz; $v_{z\text{-axis}}$ = 0.5 mm/sec; v_S = 2 mm/sec, b = 1.5 mm, FW 1.4430 (Ø 0.8mm); static positioned filler material on the tool surface

In order to calculate the resulting element-concentration in the alloyed lines using static positioned filler wires, both the volume ratio of molten material and filler material is measured in cross sections, which is specified in volume contents of BM to FW, 3.6 : 1 for filler wires with 1.2 mm diameter as well as higher volume contents 4.5 : 1 at filler material with Ø 0.8 mm. In hot forming tools steels, the element concentration of nickel and chromium is specified to a target concentration of 1.3 wt.% nickel in order to increase the hardness and 13 wt.% chromium for the improvement of resistance against scaling. Both target concentrations in combination with the hot forming steels 1.2379 and WP7V can be reached using the filler wire material FW1.4430 and FW 1.4316, see Table 2.

Table 2: Analytical calculated element concentration of base material and alloyed lines after laser alloying and martensite start and – finish temperature; P_L = 500 W, f = 50 Hz; $v_{z\text{-axis}}$ = 0.5 mm/sec; v_S = 2 mm/sec, b = 1.5 mm, FW 1.4430 (Ø 0.8mm); static positioned filler material on the tool surface

Base material and filler wire		Cr [wt.%]	Mo [wt.%]	V [wt.%]	Ni [wt.%]	Mn [wt.%]	C [wt.%]	M_S [°C]	M_F [°C]
BM: 1.2379	Chemical composition of BM	12	0.8	0.9	-	-	1.55	-	-
	FW: 1.4316 (Ø1.2mm)	13.8	0.6	0.7	2.0	0.4	1.22	-	-
	FW: 1.4430 (Ø0.8mm)	12.7	1.0	0.8	1.2	0.2	1.3	-	-
	FW: 1.4430 (Ø1.2mm)	13.4	1.2	0.7	2.4	0.3	1.23	-	-
BM: WP7V	Chemical composition of BM	7.8	1.5	1.5	-	-	0.5	547	332
	FW: 1.4316 (Ø1.2mm)	10.6	1.2	1.2	2.1	0.4	0.39	508	293
	FW: 1.4430 (Ø0.8mm)	9.0	1.6	1.3	1.2	0.2	0.45	526	311
	FW: 1.4430 (Ø1.2mm)	10.1	1.7	1.2	2.5	0.3	0.4	506	291

In dependence on the analytical calculated element concentration of the alloyed lines, the martensite start temperature (formula 1) is computed, which declines with rising element concentration, especially with carbon content. Due to the fixed volume of alloyed material using filler wires, which are positioned statically on the tool surface, the calculated martensite start temperature declines more intense using filler wires with a diameter of 1.2 millimeter compared to 0.8 millimeter wire, because the input of alloying elements declines about 66 %. Next to the volume of filler material, also the content of elements (wt.%) influences the resulting martensite start temperature. Thereby higher contents of elements in the filler material (1.4430, Ø1.2 mm), except chromium, see Table 2, decrease the martensite start temperature for 41°K at WP7V, whereas the amount of alloying elements at the usage of a filler wire with a diameter of 0.8 millimeter only leads to a minor decrease of 21°K at WP7V of the martensite start temperature, each compared to the base material. Due to the fact, that 1.2379 belongs to the group of hypereutectoidic steel, high carbon contents are ligated in carbides and are consequently not disposable for the martensitic micro structure formation, so that a calculation of the martensite start temperature is omitted.

In order to get information about the resulting hardness in the alloyed lines, using static positioned filler wires, the hardness is measured in the alloyed structure, which is additionally marked in the cross section of Figure 7 with a black line, in the heat affected zone and the base material. To check the influence of alloying elements as well as thermal energy input concerning the resulting mechanical properties. Figure 7 shows two hardness profiles using the filler wires 1.4430 and 1.4332.

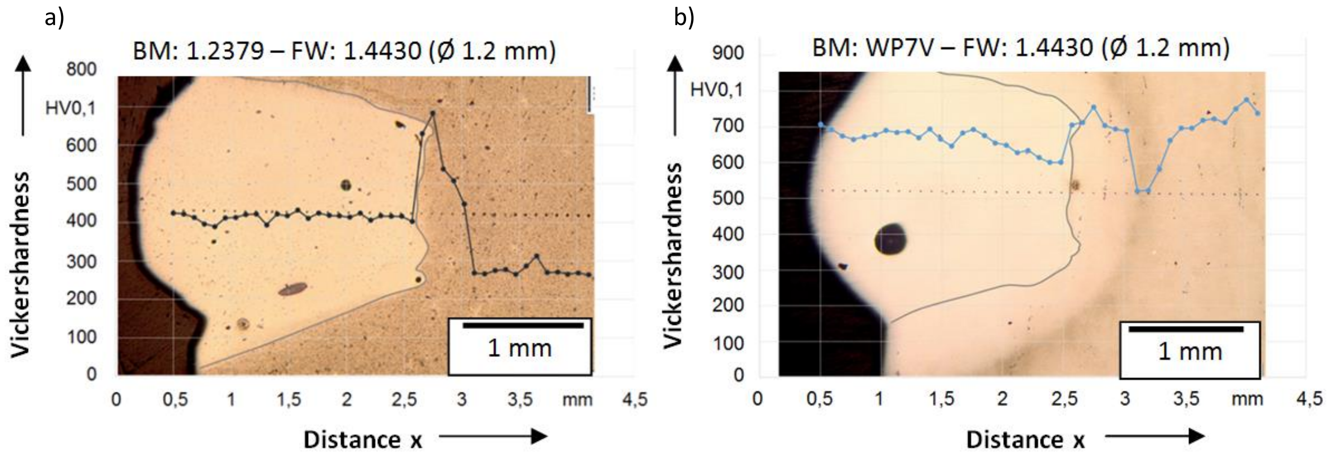

Figure 7: Micro-hardness profile of alloyed lines and base material with static positioned filler wires on the tool surface; P = 500 W; f = 50 Hz; v_s = 3 mm/sec, b = 1.6 mm; a) unhardened base material 1.2379, b) hardened base material WP7V

Comparing the micro-hardness of the alloyed lines and the unhardened base material 1.2379, according to Figure 7a), a hardness spot in the heat affected zone appears, which can be attributed heat treatment and the martensite formation with small grain sizes compared to the base material. Compared to the base material, the hardness in the rather weld zone rises up to 400 HV0.1 which conforms an enhancement of about 40 % at the usage of filler material 1.4430 with a nickel content of 12 wt.%. The base material of the hot forming steels WP7V, with a martensitic structure features a hardness of 700 HV0.1, which declines in the heat affected zone to 500 HV0.1. This can be attributed to the fact that a temperature regime in the heat affected zone is reached which is similar to a soft annealing process. Subsequent to this hardness minimum, an increase of hardness to 850 HV0.1 follows and indicates martensite formation, but has to be analysed in further investigations. Subsequent, a hardness level similar to the base material is reached in the alloyed lines in which a slight decline of hardness appears. To compare the influence of different filler wires regarding the resulting hardness in the alloyed lines, an overview of the measured hardness in the base material of hardened WP7V and unhardened 1.2379 to alloyed lines is shown in Figure 8.

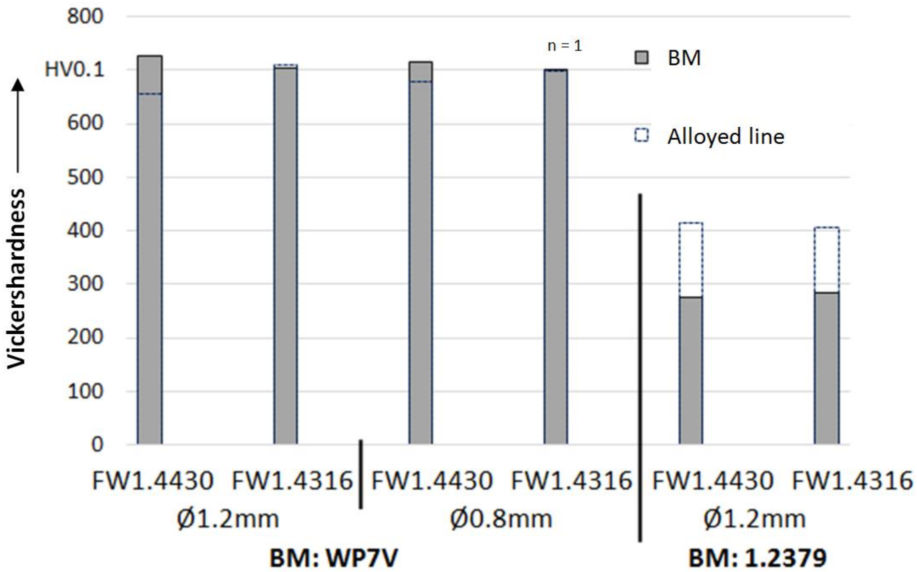

Figure 8: Average hardness in alloyed lines and base material using different filler wires; P_L = 500 W, f = 50 Hz; $v_{z\text{-axis}}$ = 0.5 mm/sec; v_S = 2 mm/sec, b = 1.5 mm, FW 1.4430 and FW 1.4316; static positioned filler material on the tool surface

A comparison of the hardness between alloyed lines and base materials shows, that nearly the same hardness value of alloyed lines and the base material WP7V results. The hardness level of the base material can be retained for laser beam alloying with filler material 1.4430 and 1.4316. This can be attributed to the alloying element nickel, which induces an increase of hardness, based on the mixed crystal formation [9]. The hardness in the alloying lines with 1.4316 filler material in combination with the hardened hot forming steel WP7V is equal to the hardness in the untreated base material. According to the higher martensitic start temperature of the filler wire 1.4316 the hardness in the alloying indicates some higher martensitic content compared to alloying line, modified with 1.4430 filler material. In contrast to that, a hardness increase of about 40 % can be reached in the hot forming tool steel 1.2379, using the mentioned filler wire material of Table 2. Due to the arising hardness minimum in the heat affected zone, which can depict some disadvantage concerning the mechanical strength of the functional tool surface, a downstream thermal hardening can recoup the hardness minimum. In order to give some evidence on the homogeneity of the mechanical properties in the whole alloyed cross section, the resulting distribution of elements, especially a potential decomposition in the crossover to the heat affected zone, is investigated. Figure 9 exemplarily shows the element concentration in the alloyed line, measured in a line scan on the cross section from the surface towards the heat affected zone and the untreated base material.

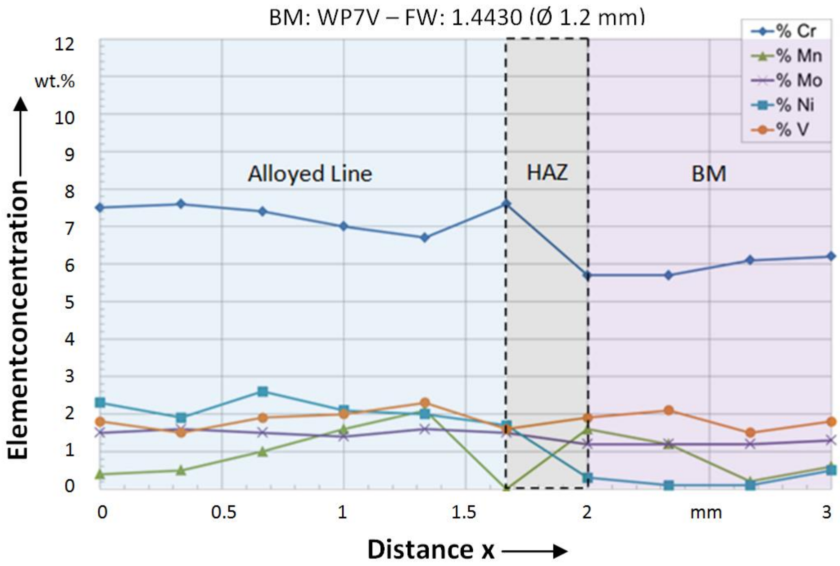

Figure 9: Element concentration in the alloying lines and base material measured with µ-X-Ray fluorescence analysis; P = 500 W; f = 50 Hz; v_s = 3 mm/sec, b = 1.6 mm; static positioned filler material on the tool surface; measurement direction analogue to the hardness measurement, see Figure 7

A homogeneous distribution of nickel and chromium can be observed. The deviation of one wt.% within the measurement line has to be optimized by adapted alloying strategies to ensure homogeneous properties over the cross section, which plays an important role to enable consistent qualities also after the machining of abraded tool surfaces. Furthermore, the elements molybdenum and vanadium have a homogeneous distribution. The concentration gradient of manganese shows an increase from the top of the alloying line towards the bottom and indicates to liquations in the structure. Therefore some further investigations regarding the melt bath dynamics using different oscillation frequencies have to be performed. In consideration of a structure modification of highly stressed tool surfaces at hot forming steels, the developed laser alloying process using circular beam oscillation presents a suitable method for a homogeneous distribution of alloying elements.

3. Conclusion

The investigations presented in this paper show experimental results regarding the development of a wire based laser alloying process and its process boundaries. Based on high speed observation of the process, the melt flow in dependence of the feed velocities can be characterized to avoid process instabilities because of a self-wetting at the loose wire end. In consideration of low wire feed velocities, the gap between the loose wire end and the specimen surface must be less than 0.2 millimeter, to provide enough filler material from the beginning of the alloying process. The wire feed tip must be positioned in an angle of incidence smaller than 35° to the specimen surface. At higher angles of incidence than 35°, a local inhomogeneous melting of the wire end arises, which leads to process instabilities with irregular melt flow. Next to the positioning requirements of the filler material, oscillation frequencies between 50 Hz and 400 Hz are feasible to enable cylindric defined melting depths at specimen feeding speeds of 2-8 mm/sec. Furthermore the structure modification using different alloying elements was investigated. Therefore the martensite start and martensite finish temperature, using different filler wire materials, in dependence of their composition and the volume of molten base material was calculated. In order to achieve a maximal martensitic content in the alloyed line, the martensite finish temperature must be above room temperature after passing the temperature interval of M_S – 215°C. Thereby the possibilities concerning a metallurgical structure modification at the usage of stationary positioned filler wires in the alloying process are investigated. The calculated resulting martensite start temperature according to Capdevila for the used filler declines for 41°K at WP7V, using filler material 1.4430 in a diameter of Ø1.2 mm, whereas the amount of alloying elements at the usage of filler wires with a diameter of 0.8 millimeter only leads to a minor decrease of 21°K of the martensite start temperature, each compared to the base material. By the usage of the unhardened base material 1.2379, which belongs to the group of hypereutectoidic steels, the martensite start temperature can not be calculated correctly. Thereby high carbon contents are ligated in carbides and are consequently not disposable for the martensitic micro structure formation, so that a calculation of the martensite start temperature is omitted. The laser alloyed structure of hardened hot forming steel WP7V features a hardness which is equal to the untreated base material, whereupon the resulting resistance against wear has to be quantified in further tribological investigations. The hardness of the unhardened hot forming steel 1.2379 can be increased until 40 % compared to the unhardened base material. The consistent distribution of all elements in the alloying line can be determined for the used oscillation frequencies and exhibits a deviation of less than one weight per cent.

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