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Influence of alloying elements on mechanical properties and defect formation at wire based laser beam alloying of hot-working tool steel

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Abstract

In order to reduce wear at hot stamping processes, the mechanical properties of highly stressed tool surfaces can be modified by applying laser beam alloying with filler wire and beam oscillation. By means of increasing the carbon content as well as the content of carbide forming alloying elements, the formation of carbides, featuring a high microhardness, can be induced. Since the use of filler materials containing carbon leads to brittle microstructural properties, the general processability of such filler wires has to be analyzed with regard to the formation of imperfections in the microstructure.
This paper discusses the influence of different alloying concepts which are suitable to increase the microhardness. Thereby the influence of the carbon content as well as the content of carbide forming alloying elements is analyzed regarding the microhardness and the crack formation. Based on the results of the investigations, recommendations for the quantitative and qualitative selection of the alloying composition as well as a process strategy are derived.

Keywords: laser beam alloying, beam oscillation, filler wire, wear resistance, hot stamping;

1. Introduction

The ongoing trend towards light weight construction in the automotive sector at simultaneously rising safety standards requires the usage of high strength bore manganese steels, which fulfill high mechanical properties and coincidental enable the reduction of sheet thickness. Especially for the manufacturing of crash relevant parts, like bumbers, b-pillar or sills, high strength bore manganese steels are suitable materials which consequently establish potential for light weight construction because of mechanical strength of about 1400 MPa. Manufacturing these parts in the press hardening process affords some completely austenitization of the blanks, which is followed by some hot forming process to manufacture the crash relevant car body parts. In detail forming and hardening of these plates is combined in one process step. However, high process forces induce high abrasive wear especially in high stressed areas of the hot stamping tools, which decreases the tool quality because of deficient dimensional accuracy of the tools. In order to improve the wear resistance of such highly stressed areas of hot stamping tools, local modification of the mechanical properties is necessary to enlarge tool life and also revision intervals. Therefore the laser beam alloying process with filler wire enables local and stress specific modification of the mechanical properties by changing the chemical composition of the material. To locally improve wear resistance of such steels, an increase of microhardness is necessary. Especially at hot forming tools steel, the

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microhardness can be increased by rising carbon content, but simultaneously also the crack formation increases. The crack formation is attributed to the carbon content in the microstructure and the distribution of the alloying elements. Especially at local carbon accumulations in the microstructure, which can be attributed to inhomogeneous mixing of the alloying elements, crack formation happens. In order to ensure a homogeneous distribution of the alloying elements, beam oscillation is superposed to the linear movement of the laser beam in order to cause some turbulent melt flow in the process zone and influence the solidification boundaries by controlled energy input. For this purpose different oscillation strategies are investigated to influence the melt pool dynamic and reach homogeneous element distribution. In Detail the melt flow dynamics and also the temperature input, which influences the cooling behavior and consequently the formation of the microstructure are influenced. Up to now, there are no investigations regarding the wire based laser beam alloying with beam oscillation. In detail the boundaries regarding oscillation strategy, which are necessary to induce a homogeneous element distribution, are unknown. Thus these issues are investigated in this paper.

2. State of the art

In order to increase wear resistance of highly stressed tool surfaces, laser beam alloying is a suitable process for a local structure modification in order to enhance tool life. Thereby a local melting of the tool surface at a simultaneous input of alloying elements allows the formation of a microstructure with adapted properties like high mechanical strength [1]. In comparison to laser beam hardening, properties like high temperature and creep strength, as well as the resistance against wear and scale can also be improved by adapting the chemical composition. Furthermore the microstructure can be modified towards ductile or brittle material properties in order to reach a combination of both characteristics at one press hardening tool located at different areas [2].

To improve mechanical properties, in detail mircohardness of such tool steels, a specific adaption of the carbon concentration as well as the concentration of carbide forming alloying elements is used. With rising carbon contents, the hardness increases whereat the toughness decreases. Furthermore, also the critical cooling velocity for martensitic transformation decreases and nearly stays constant for carbon concentrations between 0.5 wt.-% and 1.4 wt.-%. Nevertheless, high carbon concentrations typically induce some crack formation because of residual stress formation [3], [4]. Additionally local agglomeration of alloying elements, which is based on inhomogeneous distribution, is responsible for crack formation and inhomogeneous microharndess profile in the cross section of the modified structure [5]. Especially at laser processing of high carbon containing materials, a local element agglomeration can induce crack formation as well as inhomogeneous mechanical properties.

In laser based processes that involve the formation of a keyhole, three main effects dictate the flow inside the melt pool: flow around the capillary, surface tension induced flow and interactions between the gas flow inside the capillary and the surrounding melt [6]. For a process with linear beam movement this has the following implications: As there is a relative movement between laser beam and workpiece, the melt is forced around the capillary, which results in acceleration of the melt around the capillary. The maximum melt velocity is reached at the interface of the melt and the vapor capillary and the melt velocity exceeds the laser beam velocity in this region [7]. The effect of surface tension of the melt on the flow inside is referred to the Marangoni-effect and the resulting flow is referred to as Marangoni-convection. Due to temperature discrepancies between the melt pool surface and the edges of the melt pool and the sidewalls of the capillary, shear stresses are induced that accelerate the surface near melt either towards the edges or towards the middle. Marangoni-convection is predominant in heat conduction welding, whereas its influence on the melt pool dynamics is minor during keyhole welding. The last effect results from fraction at the interface of vapor capillary and melt pool. The vapor inside the capillary can transfer its impulse to the bordering melt through friction and this can induce a vertical flow of the melt that affects melt pool geometry [6]. For keyhole welding this results in an upward flow of the melt on close proximity to the vapor capillary [7]. As a consequence, melt behind the rear wall of the keyhole gets accelerated from the bottom towards the surface. On this way up the melt is also subject to the flow around the capillary and is consequently driven towards the rear end of the melt pool. Slightly below the surface at the rear end of the melt pool, the Marangoni-effect leads to a flow that accelerates melt down to root again, resulting in a recirculation of the material [7]. This demonstrates that the three-dimensional flow inside the melt pool cannot be assigned to single mechanisms and has to be considered as result of the superposition of all three mechanisms. The situation is different, if the linear relative motion between workpiece and laser beam is combined and superposed with an oscillating movement. By oscillating in a circular motion, the vertical flow induced by the vapor capillary is reduced noticeably due to shorter interaction time between melt and vapor as well as the reduced energy per unit length [7]. Additionally, an oscillating motion leads to wider melt pool in comparison to a stationary beam. Therefore, the flow directed towards the rear end of the melt pool is reduced significantly as the channel between capillary and the edges of the melt pool is larger. However, as there is melt displaced locally by the capillary the flow around the vapor capillary adds a circular motion to the melt that is accelerated towards the rear end. The Marangoni-effect was found to be of negligible influence when a circular oscillation is used [7].

In order influence the homogeneity of the alloying elements, especially for laser material processes with different material combinations, some dynamic beam motion is superimposed to the linear movement of the beam. This enables the influencing of fluid dynamic to increase the weldability of hard to weld materials or the mixing of alloying elements. Furthermore, beam oscillation is also used to enlarge the gap bridge ability, which is investigated by Rubben at al. and the microhardness gradient in the weld seam at laser beam welding of Ti-6Al-4V [8] or to reduce melt ejections at laser beam welding of zinc or copper containing alloys ([9], [10] et al., 11). Hofmann et al. and Wang investigated that circular beam oscillations induce the strongest stirring effect compared to transverse and longitudinal beam oscillations [12] in order to distribute the alloying elements homogeneous in the process zone [13]. In [14] the electron beam welding of carbon containing steels using beam oscillation is protected by letters patent. Thereby different beam oscillation strategies are named to induce bainitic solidification of the microstructure. Besides to the already mentioned investigations regarding the thermal influene of solidification behavior at laser beam welding of steel, laser beam oscillation is also used to affect melt mixing at laser beam welding of copper aluminum connection for battery contacting. Thereby the beam oscillation is used to adjust the melt intermixture, especially to avoid some brittle phase formation [15, 16].

Since the influence of the focus position, the spot diameter and the shielding gas in case of linear beam guidance [17] have been investigated up to now, it is still not understood which melt pool dynamics are necessary in the laser material processes with dynamic beam oscillation in order to achieve a homogeneous element distribution. The investigations regarding the thermal influence of solidification behavior using beam oscillation are focused on laser welding processes without filler wire. Up to now it is still not understood, how melt pool dynamics can be affected by beam oscillation and which characteristic melt pool dynamics are required to induce some homogeneous distribution of the alloying elements. Furthermore the influence of the oscillation strategy on the growth of dendrites is unknown, which are responsible for some crack-free solidification. Especially at laser beam alloying processes with filler wire, the process zone only features an unilateral opening and also high lane chamber in combination with high remelting depths, the melt pool dynamic changes significantly. Due to the fact that solidification conditions are unknown for the mentioned boundary conditions, the present paper investigates the influence of different oscillation strategies and carbon concentrations with regard to the aim of influencing the melt pool dynamics and the resulting element distribution as well as microstructure formation.

3. Experimental setup

The laser beam alloying process was conducted using a diode pumped continuous wave Yb:YAG fiber laser IPG YLS-1000 featuring a maximum beam power of 1 kW. The laser power is guided by a 14 µm optical fiber to the 2D laser scanner, which features a focal length of 165 mm. In order to ensure a perpendicular impact of the laser beam, a f-theta lens is adapted after the galvanometric controlled mirrors of the scanning head. For the appropriation of the filler wire, a wire feeding system is used, which enables feeding velocities between 0.1 and 20 m/min.

For experimental investigations, the specimens are handled using a x-y-axis system, which enables an individual adjustment of the processing speed between 1 and 14 mm/sec. The filler material, featuring a diameter of 1.0 mm, is guided in leading position into the process zone using a feeding unit FD 100 LS-WB by DINSE, which controls the feeding velocity. The longitudinal axis of the wire feeding nozzle is in alignment with the process direction and encloses an angle of about 30° to the specimen surface. To avoid the influence of atmospheric gases on the surface of the melt pool, an argon shielding gas atmosphere is generated with a flow rate of 35 l/min. Fig. 1 shows the schematic description of the laser beam alloying process including the wire feeding tip and the scanning device featuring the dynamic beam oscillation.

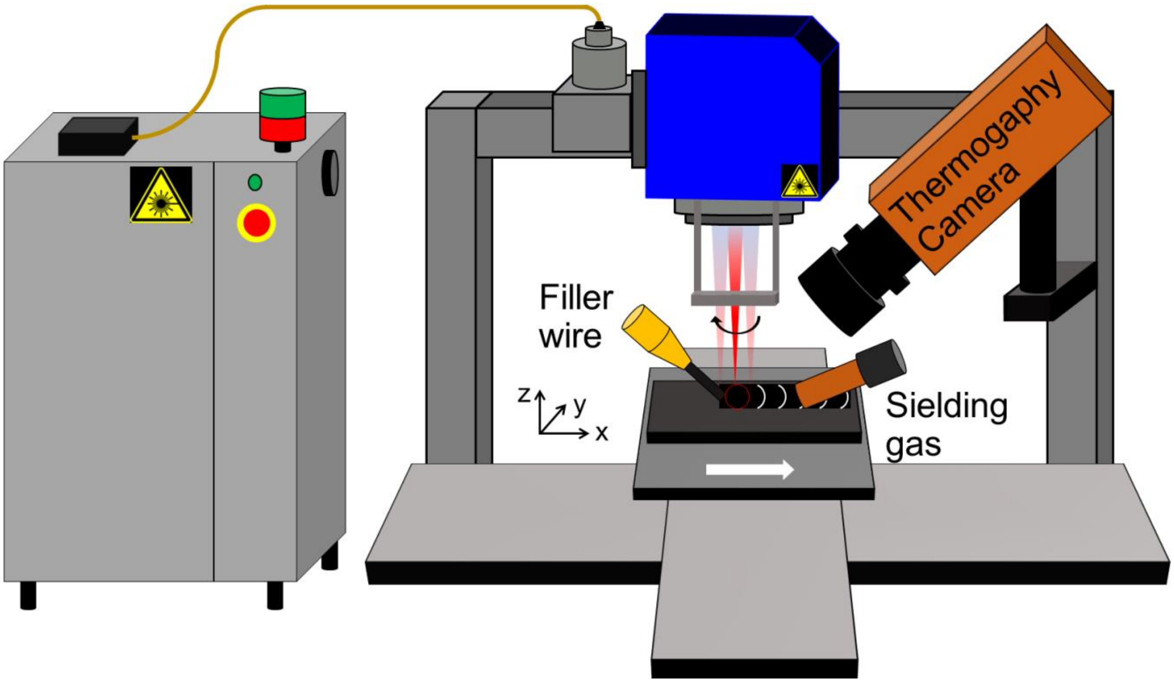

Fig. 1. Schematic description of experimental setup for wire based laser beam alloying process and thermographic process observation

Thermographic imaging and high speed imaging with appropriate frame rates can therefore be used to identify the dynamic and streaming directions of the melt flow in the process zone induced by different oscillation strategies. In detail the resulting temperature differences that occur on the surface of the melt pool because of filler wire input are detectable. Nonetheless, this can only serve as an approach to characterize the flows that are visible on the surface, whereas the situation below the surface cannot be assessed. The used frame rate for this thermographic inspections was approximately 800 fps with a frame size of 160*192 px (width*height).

For the experimental investigations, a hot forming tool steel WP7V is used, which features a thickness of 10 mm, a length of 80 mm and a width of 40 mm. The specimen are fixed by a clamping device, which is positioned at the top of a x-y-axis cross table and moved with an axis speed of 6 mm/s. The filler wire 1.3348, produced by ALUNOX, contains suitable alloying element concentrations in order to increase the carbon concentration and the content of carbide forming alloying elements. The chemical compositions of base material and filler wire are given in Table 1.

Table 1. Chemical composition of base material WP7V and filler wire 1.3348; [18], [19]

Material	**C [wt.-%]**	**Cr [wt.-%]**	**Mo [wt.-%]**	**V [wt.-%]**	**Mn [wt.-%]**	**Wo [wt.-%]**	**Si [wt.-%]**
Base material: WP7V	0.4	7.8	1.5	0.9	-	-	-
Filler wire: 1.3348	0.9	4.0	8.5	2.0	0.3	1.8	0.3

Hofmann et al. and Wang found that circular beam oscillations induce the strongest stirring effect compared to transverse and longitudinal beam oscillations [12] in order to distribute the alloying elements homogeneously in the process zone [13]. Furthermore, this kind of beam oscillation also enables the formation of some appropriate shape and surface quality of the alloying track. For the experimental investigations an oscillation amplitude of about the double wire diameter is used. To investigate the influence of the oscillation frequency on the melt pool dynamics, a variation between 50 Hz and 200 Hz is done. Consequently different energy inputs per unit length relating on the oscillation figure result, so that different geometrical shapes of the alloying line occur. These are analysed regarding width and depth.

For the experiments, different line masses are used to adapt the carbon content in the microstructure. In order to investigate the influence of the alloying element concentration on the resulting mechanical properties, different line masses from 1.7 g/m up to 6.8 g/m are implemented into the process zone. Besides the variation of the line mass, also the oscillation frequency is varied in order to investigate the element distribution. Thereby a convenient geometry of the process zone is investigated which enables a homogeneous solidification of the melt without crack formation. Due to the fact, that the solidification boundaries, in detail the shape of the process zone, are responsible for crack formation in dependency of the carbon content, the influence of energy distribution, which is influenced by oscillation amplitude and frequency are analyzed regarding solidification behavior. Furthermore, also the distribution of the alloying elements in dependency of the oscillation strategy with its resulting melt pool dynamics is analyzed to identify a beneficial oscillation strategy which enables homogeneous element distribution in the process zone. To investigate the distribution of the alloying elements, the element concentrations are measured using wavelength-dispersive X-ray spectroscopy at nine single measurement fields in three areas over depth. Due to technical limitations in measurement, the carbon concentrations are calculated by the degree of dilution.

4. Results and Discussion

4.1. Line mass and carbon concentration

In order to investigate the influence of the line mass on the resulting element distribution and the carbon concentration regarding the microstructure, different wire feed rates are applied in the alloying process. This enables the identification of the critical carbon content whereat some crack formation appears. Fig. 2 shows the cross section of the alloying lines, which are processed with different line masses.

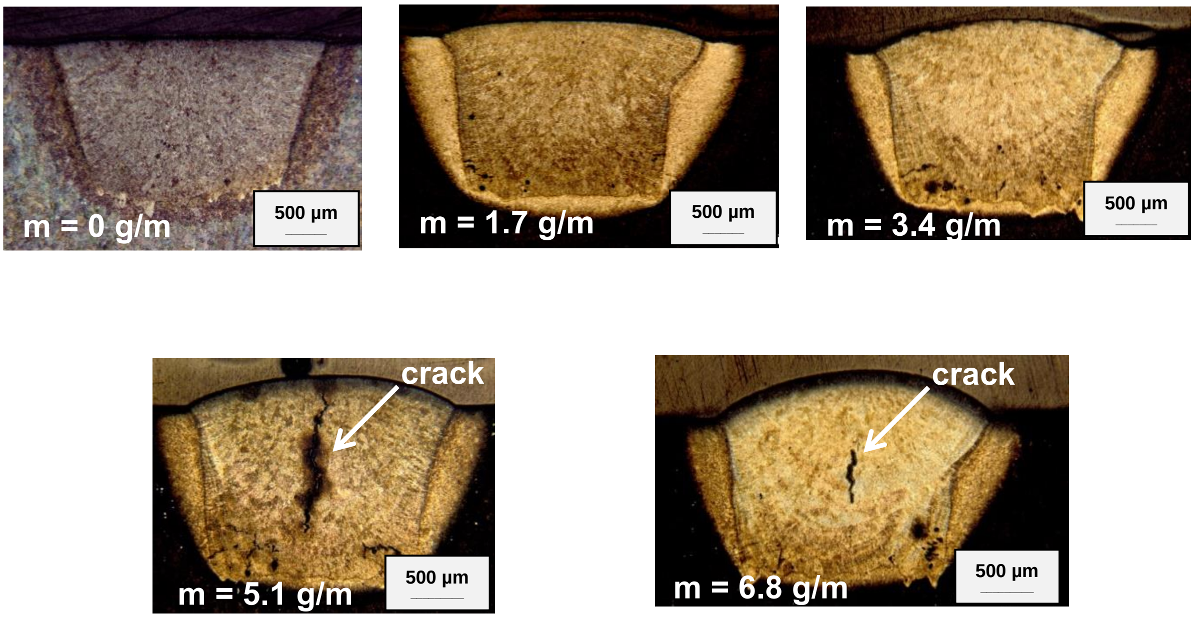

Fig. 2. Cross sections of alloying lines; P_{Laser} = 800 W; v = 6 mm/s; $\emptyset_{Amplitude}$ = 2.0 mm; $\emptyset_{wire}$ = 1.0 mm; m = 3.3 g/m; f = 50 Hz; Shielding gas: Argon 4.6; Line mass m is varied between 0 g/m and 6.8 g/m

Depending on the line mass, which is applied to adapt the carbon concentration in the alloying line, different microstructures, featuring characteristic mechanical properties, result in the modified structure of the specimen. In detail the oscillation frequency of 50 Hz in combination with a line mass of 1.7 g/m whereat a carbon concentration of 0.55 ± 0.01 wt.-% results, induces some crack free microstructure. Thereby a microhardness increase of about 20 % reaches a mean value of 835 ± 39 HV0.5 in the alloying line. With rising carbon content up to 0.57 ± 0.01 wt.-%, some slight crack formation appears in the bottom of the alloying line at 3.4 g/m. This can be attributed to inhomogeneous element distribution. Additionally indications of an irregular mixing of the alloying elements can be observed. The resulting microhardness value can be specified to 869 ± 29 HV0.2. Especially at carbon concentrations of about 0.60 ± 0.01 wt.-%, which results at line masses of 5.1 g/m, the content of brittle microstructure increases, which impacts the crack formation. Thereby a microhardness mean value of about 900 ± 20 HV0.2 results.

In general, the rising carbon concentration induces the formation of residual tensile stresses in the microstructure. Due to the fact, that solidification and growth of dendrites happens from the lateral solidification lines to the center, a tensile stress area is formed especially in the carbon agglomerations. Once the melt pool is solidified completely, the maximum of residual tensile stress is reached. After that, the stress relaxation happens, which is expressed in the formation of a tension crack. Despite of small differences of the carbon concentration in the alloying line, the processability declines. Since the carbon concentration exceeds the value of about 0.57 wt.-%, a crack formation appears at laser beam alloying of hot forming tool steels using beam oscillation of 50 Hz.

In order to characterize the intermixture of the alloying elements in the process zone, the contents of martensitic and austenitic structures are used for appraisement. Especially with rising carbon concentrations, the content of martensitic structure decreases, because carbon reduces the martensite start temperature significantly. Consequently the microstructure appears bright, which enables a assessment of melt intermixture in the processes zone. In Detail a main stream of melt is limited to the upper half of the alloying line, whereat no significant change of melt stream can be identified with increasing line mass. Based on the circular movement of the laser spot, a semicircular shape is emerged in the microstructure, which is highlighted with dotted lines in Fig. 2. This indicates to a main stream of melt, which does not reach bottom of the alloying line. Consequently, the mixing of alloying elements suffers from insuffient dynamics of melt pool dynamics, which cannot be compensated by diffusion in order to adjust a concentration balance. Furthermore, the melt pool dynamics changes with increasing line mass. This can be attributed to the decreasing melt pool depth and the rising line chamber. In detail, the melt pool turbulence is limited to a main stream, which can be characterized as lenticular shaped preferably flow. With increasing line mass, this main stream of melt flow is moved to the surface of the melt pool, but simultaneously enlarges the width of the process zone. Finally, the homogeneity of alloying element intermixture to the base material decreases with increasing line mass. Additionally, also the crack formation increases with rising carbon concentration and decreasing melt pool turbulence. Consequently the effect of oscillation frequency is analyzed regarding the controlled influencing of melt pool dynamic to induce suitable melt stream conditions, which enlarge the melt flow towards the bottom of the alloying line.

4.2. Oscillation frequency

In order to investigate the influence of different oscillation frequencies on the solidification conditions at laser beam alloying processes with carbon containing filler wire, the microstructure is analyzed regarding crack formation. Based on the orientation of the dendrites, which is analyzed in the microstructure, the solidification behavior can be described detailed. Fig. 3 shows two cross sections of alloying lines, which are processed with different beam oscillation frequencies.

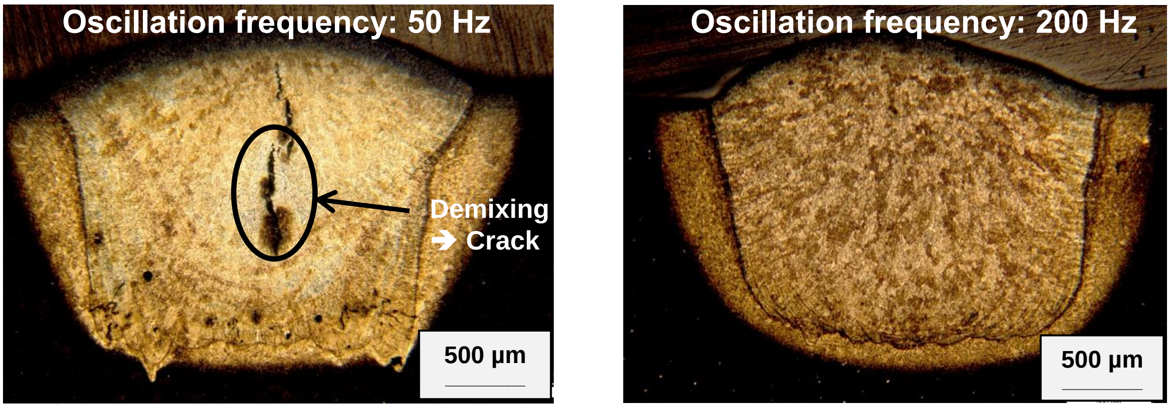

Fig. 3. Cross section of alloying lines; P_{Laser} = 800 W; v = 6 mm/s; $\varnothing_{Amplitude}$ = 2.0 mm; $\varnothing_{wire}$ = 1.0 mm; m = 5.1 g/m; Shielding gas: Argon 4.6; Left: frequency of circular oscillation: f = 50 Hz; Right: frequency of circular oscillation: f = 200 Hz

The comparison of both cross sections shows a vertical crack formation in the center as well as some small cracks in the bottom of the alloying line, which features a horizontal orientation parallel to the surface of the specimen. Due to a inhomogeneous distribution of the alloying elements, which appears especially in the center of the alloying line, crack formation follows. Based on local segregations and distinctive flow marks, the turbulence in the process zone can be described. Especially the change of microstructure in the bottom of the alloying line indicates an inhomogeneous mixing of the alloying elements in the process zone. These dark areas are caused by a martensitic structure, which is preferred formed because of a lower carbon content compared to the structure in the center of the alloying line. Due to high alloying element contents, high residual austenite contents result, which features a brightly microstructure. Consequently, the oscillation frequency of 50 Hz leads to an inhomogeneous mixing of the alloying elements because of some limited effect of melt pool turbulence towards melt intermixture until the track bottom. In contrast to low oscillation frequency of 50 Hz, an increase of the frequency up to 200 Hz changes the spatiotemporal energy input and the resulting melt pool turbulence. Consequently the homogeneity of the element distribution increases. This enables a homogeneous solidification of the melt without formation of critical residual stresses. Consequently the solidification behavior can be influenced by adapting the energy input per unit length to influence the melt pool dynamics with regard to the mixing of the alloying elements.

In contrast to that, the microstructure of the alloying lines, which are processed using 400 Hz beam oscillation frequency, feature a homogeneous dendritic structure. In detail, the contents of martensitic and residual microstructure are evenly distributed, which indicates a homogenous mixing of the alloying elements. Especially with increasing beam oscillation, the turbulence in the process zone increases, so a mainstream of the melt reaches the bottom of the alloying line. Next to the analysis of the microstructure of cross sections, which was used to describe the melt flow conditions in the process zone below the specimen surface, the melt pool dynamic is also analyzed using thermographic inspections. In this context, only the temperature differences are used to figure out the melt flow dynamic, whereat the absolute temperature values are not of interest. The section observations can be positioned to melt pool. In order to describe the melt pool dynamic in detail, different characteristic positions for example at 0°, 90°, 180° and 270° are used to characterize the melt stream behavior for one complete circulation. Fig. 4 shows a picture sequence, which is used to plot one complete spot circulation.

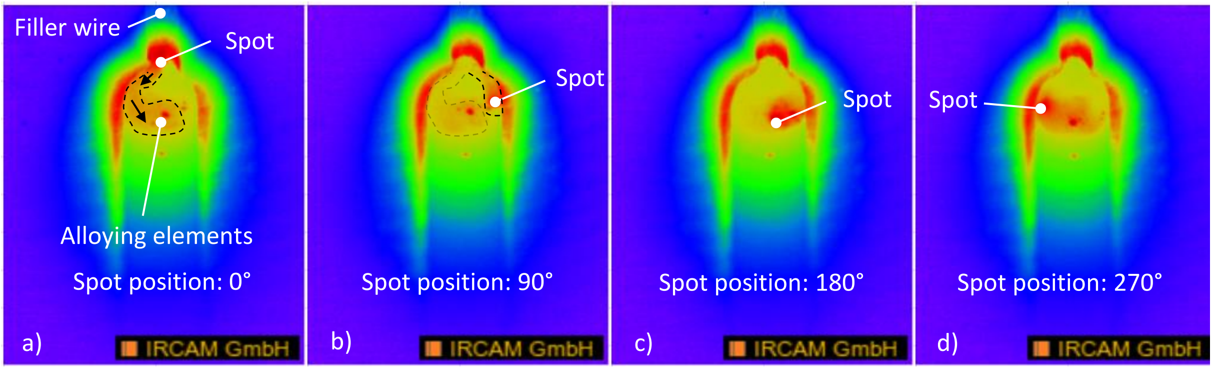

Fig. 4. Description of melt pool dynamic using some false color representation of a thermographic inspection; Top view of process zone at different positions of laser spot at circular oscillation; P_{Laser} = 800 W; v = 6 mm/s; $ø_{Oscillation\ amplitude}$ = 2.0 mm; frequency of circular oscillation: f = 50 Hz; $ø_{wire}$ = 1.0 mm; m = 3.3 g/m; v_{FW} = 0.3 m/min; Shielding gas: Argon 4.6

Due to the fact that dynamic melt flow is hard to visualize, a sequence of standing images is used to characterize the melt flow dynamics in dependencey of the laser spot position. In general, the melt flow dynamic can be separated into two main characteristic observations. The first one is the melt flow in direct proximity of the capillary. In detail, the melt is displaced lateral, because of its dynamics and the process movement. Subsequent to the keyhole, the melt follows the capillary because of suction. Every time the laser beam reaches the filler wire, some flow towards of the respective side of the melt pool is generated, which can be visualized because of temperature differences and also differences in chemical composition. As a result from being obstructed in this direction by the back wall, the flow follows a slight curvature along the edge of the melt pool into the center. During this motion the beam has already moved to the 90° position of the oscillation, see picture 4 b). Despite some addition of melt flow in the process zone, the area, which contains the high amount of alloying elements from the filler wire is still existing. The beam motion therefore causes a flow that is directed along the edge of the melt pool and curved towards the center of the melt pool. If a certain amount of melt is accumulated in the center of the oscillation contour, the capillary induces a melt drift to the back wall of the process zone towards the solidification line. As the laser spot reaches the 90° position in the oscillation contour, a backflow of melt appears at the back wall. Additionally at the spot position of 180°, the melt flow direction in the subsequent melt bath changes and forms a counter rotating stream. Consequently the melt flow during one circulation can be described as turbulent flow for laser alloying processes with beam oscillation in combination with filler wire. In analogy to the melt flow analysis on the base of microstructure, the circular dynamics, which forms the main stream of the melt pool dynamic can be confirmed. In addition, it can be noted, that with decreasing melt pool dimensions, the turbulence in the process zone increases and becomes increasingly arbitrary.

In comparison to the beam oscillation frequency of about 50 Hz, the influence of increased oscillation frequency is analyzed towards the resulting melt pool dynamic. Especially the differences regarding the turbulence are analyzed to draw a comparison to the oscillation frequency of 50 Hz. Fig. 5 shows a picture sequence of one complete spot circulation at an oscillation frequency of 200 Hz.

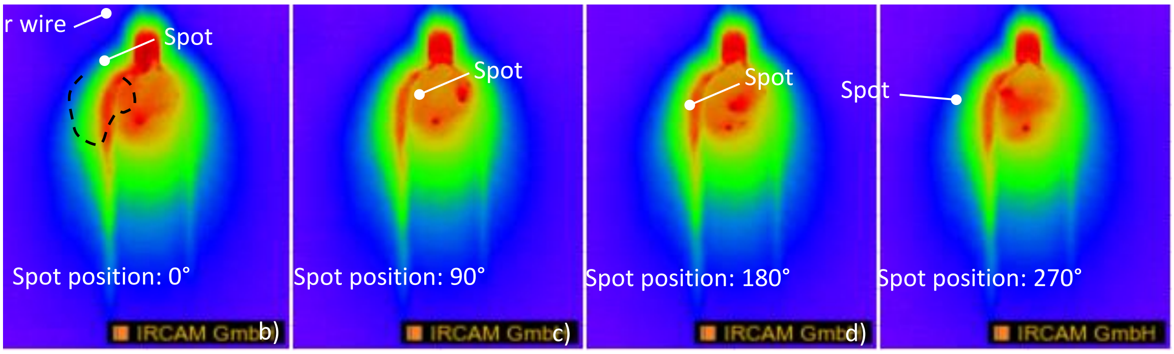

Fig. 5. Description of melt pool dynamic using some false color representation of a thermographic inspection; Top view of process zone at different positions of laser spot at circular oscillation: resolution: 160x192; 800 fps; P_{Laser} = 800 W; v = 6 mm/s; $ø_{Oscillation\ amplitude}$ = 2.0 mm; frequency of circular oscillation: f = 200 Hz; $ø_{wire}$ = 1.0 mm; m = 3.3 g/m; v_{FW} = 0.3 m/min; Shielding gas: Argon 4.6

Compared to the resulting melt bath dynamics at low oscillation frequencies, some different turbulence results in the process zone at an oscillation frequency of about 200 Hz. As a result, the molten filler material is distributed in the process zone in a significantly larger area. As soon as the spot has passed a quarter circulation after melting, the added filler material is spread over the entire process zone. In comparison to oscillation frequencies of 50 Hz, a crater formation can be observed in the videos, which indicates very high circular melt stream motion. Thus the appearance of the crater also disappears because of frequent direction changes. Furthermore at the laser spot position of 0°, a counter rotating melt flow can be observed. As a result, an increasing melt stream velocity and turbulence of the melt results with increasing oscillation frequency. Consequently the increased melt stream velocity induces an increased turbulence of the complete melt pool volume which ranges down to the track root.

In order to characterize the element distribution in dependency of the oscillation frequency, some wavelength dispersive element analysis is done at nine different positions over width and depth. These are evenly distributed over the cross section. Due to the fact that carbon proves to be inappropriate for some quantitative analysis because of specific boundaries in the measurement equipment, molybdenum is used for characterization. Fig. 6 shows the averaged molybdenum concentrations for different line masses and oscillation frequencies.

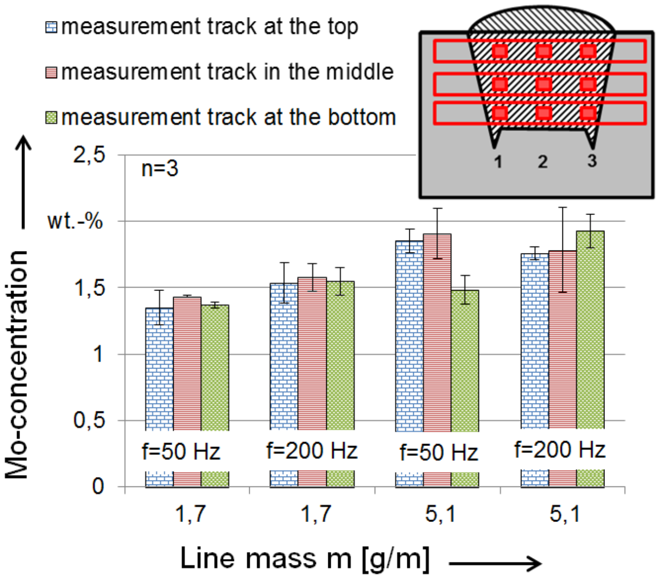

Fig. 6. Molybdenum concentration for different line masses and oscillation frequencies; P_{Laser} = 800 W; v = 6 mm/s; $ø_{Oscillation\ amplitude}$ = 2.0 mm; $ø_{wire}$ = 1.0 mm; Shielding gas: Argon 4.6

Applying low line masses in combination with low oscillation frequency of 50 Hz, high variations of the molybdenum content result. With increasing line mass, the molybdenum concentration increases over the depth of the alloying line because of insufficient melt bath dynamics. With increasing oscillation frequency, the differences in element concentration decreases to 0.2 wt.-% compared to 0.5 wt.-% at oscillation frequencies of 50 Hz. Due to the fact that higher oscillation frequencies increase the turbulence of the melt in the process zone, the homogeneity of the element distribution increases. Consequently suitable melt pool dynamics are induced in order to reach a homogeneous distribution of the alloying elements, which enables crack free microstructures in the alloying line.

5. Summary

In order increase the wear resistance of highly stressed hot forming tool steels, some local structure modification is used to change the mechanical properties. Therefore some selective increase of the carbon concentration is used to increase the microhardness. Due to the high suspectibility towards crack formation which is attributed to local carbon agglomerations, an appropriate laser beam oscillation strategy is developed to reach some homogneous distribution of the alloying elements in order to significant microstructure with cracks. Especially with rising line mass of the applied filler wire, the melt stream conditions for some homogeneous distribution are getting inappropriate. In order to induce some directional solidification without element agglomerations, the homogeneity of the alloying elements in the melt bath can be influenced convenient with increasing oscillation frequency. The present work shows the possibility to influences to the melt pool dynamcis by applying beam oscillation. Especially for oscillation frequencies of 200 Hz at circular oscillation, the maximum differences of the alloying element concentration can be quantified to 0.2 wt.-%. For further investigations, the influence of point shaped oscillation strategies is analyzed regarding the melt intermixture. Additionally high speed imaging is used to get some detailed information about melt flow behavior especially for characterizing demelting of filler wire and also melt flow behavior in the process zone.

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