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Investigation of the Effect of Process Parameters on the Break of Laser-welded Drill Bits

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Abstract

The geometry and microstructure of the seam can be influenced by changing technological parameters such as laser power, welding speed, focus distance and shielding gas. In this research we examine the effect of laser power and focus distance on the quality of the breaking torque value while the welding speed and the shielding gas is unchanged. From the test results, we found that changing the defocus has no effect; a change in laser power affects ~15 %, while a change in welding position significantly affects the breaking torque.

Keywords: *laser welding, diamond segment, material testing, parameter study.*

1. Introduction

Laser beam welding has several advantages due to its concentrated nature: low heat input, a narrow heat affected zone, small distortion and easy automation. Compared to conventional welding processes, it produces deeper melting, higher welding speed, accuracy, reliability, efficiency and higher productivity [1]. Metal based materials of different material qualities can also be welded by laser beam if the two metals can simultaneously melt and form a common melt [2]. The weld geometry and micro-structure can be influenced by changing the technological parameters.

In our previous article [3] we have already investigated laser beam welded joints of diamond segment drill bits, searched for welding defects. Possible alloys and microstructure and hardness tests were performed. Additionally, in this research, we welded powder metallurgy segments onto thin-walled steel tubes, we used the same components for the sample production as for the serial production. The different effect of the laser welding process parameters was investigated separately onto the mixed joints fracture test values. This value is included in the current drawing specifications and is used to qualify laser-welded joints in serial production.

2. Conditions for the experiments

Laser welding process parameters, such as laser power, welding speed, focus distance and shielding gas have the greatest influence on the quality of welded joints [4]. In this series of experiments, besides the laser power, the effect of the change of the focus distance was investigated not only perpendicular direction to the surface (defocus) but also axial direction (welding position) (Figure 1), because when welding two components, the shift of the laser beam affects the joint strength.

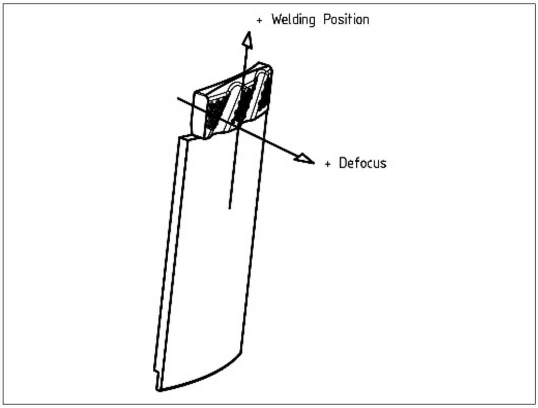

Figure 1. *Focus spot shifting directions*

The experiments were performed with a Trumpf TruDisk 4002 laser source, which has max. 4 kW power and beam wavelength of 1.03 µm. The segments were welded to a thin-walled cold drawn tube of material quality 1.0308 according to EN 10305-1 [5], with a wall thickness of 2±0,15 mm. The chemical composition of the segments: Astaloy-Mo powder = 99.8 %, Graphite powder = 0.2 %, and the chemical composition of the tube: C ≤ 0.17 %, Si ≤ 0.35 %, Mn ≤ 1.2 %, P ≤ 0.025 %, S ≤ 0.025 %.

Possible strategies for experiments:

– Best-guess approach is often used, but it is unsure that we can find the optimal solution. If we find a reasonably good solution, we need not keep guessing;
– Change one factor at a time is an easily reproducible procedure, but a large number of experimental steps are required, the interaction of the individual factors is not apparent from the experiment and interfering effects cannot be taken into account during the study;
– Factorial Experiments; changing several factors at the same time (fewer experimental steps required), the interaction of each factor is also apparent from the experiments. It is possible to calculate the average values and so-called effects associated with the settings.

To perform the experiments, we chose the change one factor at a time method. From the results obtained, we will be able to select the range within which it is worth conducting the factor experiments in order to understand the interaction of the parameters.

3. Results achieved

3.1. Test method used

The purpose of the test was to determine the average torque required to break out the segment, which should be greater than the required minimum 9 Nm. To determine the breaking torque value, we placed an insert that fitted the shape of the segment, which connected to digital display torque wrench (Figure 2). After setting the torque wrench at zero, the segment broke in an outward direction and the displayed value was read.

We broke 16 pcs of segments from each sample and evaluated the results with the Minitab software. An average breaking torque value applies to our specification ($\overline{X}$) but it is also important for us to have a lowest breaking torque value (min) to ensure that each bond meets the requirement. In addition, standard deviation (σ) and process capability (Cpk) were determined. The value of the latter shows how central to the mean and how far each value is relative to the tolerance. (Figure 3). The process capability index has two parts: upper process capability index (1) and lower process capability index (2). Cpk (3) is the smaller of the two [6]. In our case we just calculated with (1) because the tolerance in the classical term is a one-sided tolerance with a minimum requirement of 9,5 Nm.

If Cpk value is:

– > 1, the process is satisfactory, below which it does not meet the minimum requirements;
– ≥ 2, then the process is as expected, the number of defective pieces is approx. 5 PPM;
– ≥ 5, the process is redesigned (there is no need for such good quality or any additional cost involved).

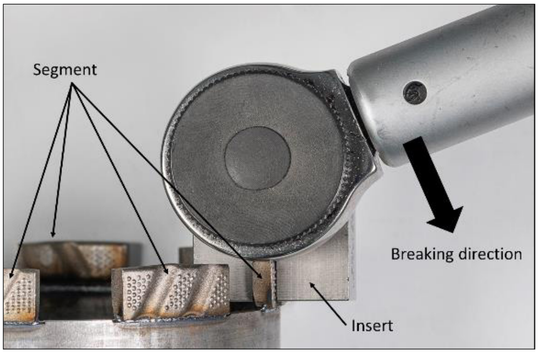

Figure 2. *Tools needed to determine the breaking torque value*

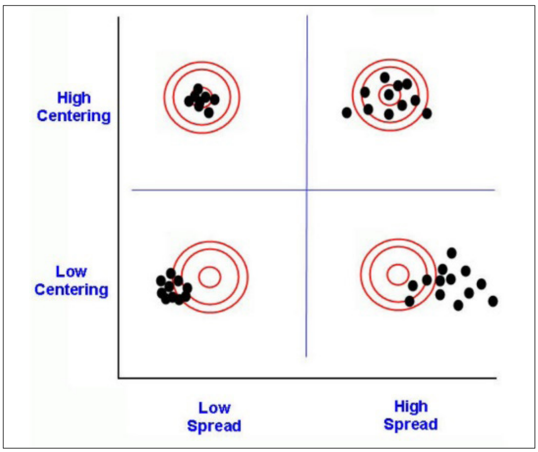

Figure 3. *Relationship between process spread and centrality (Symbols in the figure: black dots show the measured values; the red circles show the tolerance fields and the intervention limit)* [7]

$$C_{PL} = \frac{Mean\ value - Lower\ tolerance}{3 \times Deviation} \quad (1)$$

$$C_{PU} = \frac{Upper\ tolerance - Mean\ value}{3 \times Deviation} \quad (2)$$

$$C_{PK} = Min(C_{PL}, C_{PU}) \quad (3)$$

The initial value was set to 0.25 mm defocus and (−0.2) mm welding position, the welding speed was set to the maximum value that could be set on the laser welding device, 3 m/min during the experiments.

3.2. Results and their evaluation

The laser power was reduced in increments of 10% until the tube had just melted completely, this was achieved in Sample Nr. 5 (at 45% laser power). The data is shown in **Table 1** and the graphical representation is shown in **Figure 4.** The breaking torque values were varied in between 2 Nm in the power range of 45–70 %. The lowest standard deviation, the highest machine index and highest breaking torque index occurred at 60 % power. However, 45 % laser power for the melting criterion was considered for further experiments since this parameter is immediately visible if the tube does not melt through on the entire cross-section due to focus spot offset.

The defocus was varied in increments of 1mm starting from the surface (positive direction) and then, in 0.5 mm increments was moved below the outer surface of the tube (negative direction). The data is shown in **Table 2.** and the graphical representation is shown in **Figure 5.** The positive defocus has a negative effect on the breaking torque index, but as a result of the negative defocus provides changes on the breaking torque values within 1.4 Nm range. For the analysis of the welding position, the parameter with the highest machine capability index was chosen (Sample No. 7).

The welding position was varied in increments of 0.1 mm from the segment edge in the direction of the tube. The data is shown in **Table 3.** and the graphical representation is shown in **Figure 6.** The welding position away from the edge of the segment increases the breaking torque value, and when the maximum is reached, the standard deviation increases, and in parallel, the breaking

Table 1. *Change of breaking torque values as a function of laser power*

Sample sign	$\overline{X}$ (Nm)	σ	Cpk	min (Nm)
1 (70 %)	17.575	1.640	2.65	12.1
2 (60 %)	19.506	0.589	3.68	17.4
3 (50 %)	18.793	2.216	1.78	11.1
4 (40 %)	14.773	0.611	2.84	13.7
5 (45 %)	17.620	1.108	2.56	14.3

Table 2. *Change of breaking torque values as a function of defocus*

Sample sign	$\overline{X}$ (Nm)	σ	Cpk	min (Nm)
6 (1.25)	13.431	1.271	1.58	10.1
7 (−0.75)	17.731	0.690	4.69	16
8 (−1.25)	17.818	1.104	2.74	15.5
9 (−1.75)	17.275	1.025	2.39	15.6
10 (−2.25)	17.086	1.823	1.73	11.7
11 (−2.75)	16.433	1.848	1.35	10.9

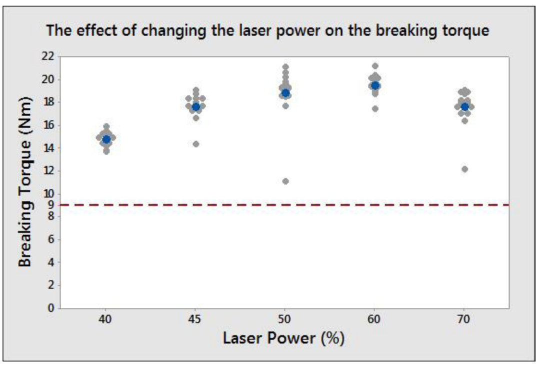

Figure 4. *Change of breaking torque values as a function of laser power*

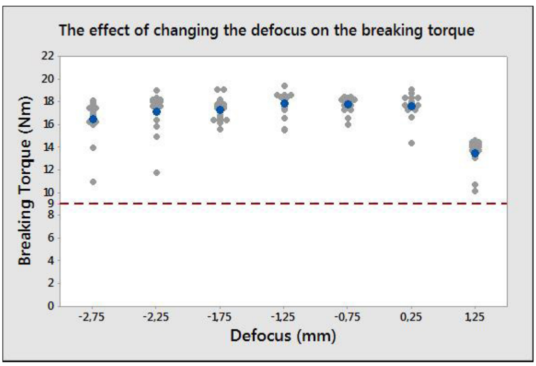

Figure 5. *Change of breaking torque values as a function of defocus*

Table 3. *Change of breaking torque values as a function of welding position*

Sample sign	$\overline{X}$ (Nm)	σ	Cpk	min (Nm)
13 (0)	13.025	1.105	2.05	11.2
14 (−0.1)	15.500	1.044	2.59	14.2
15 (−0.3)	14.450	2.134	0.89	10.4
16 (−0.4)	3.612	5.106	−0.39	0
17 (−0.5)	0			0

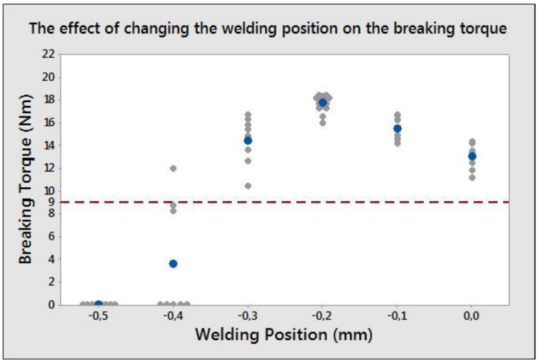

Figure 6. *Change of breaking torque values as a function of welding position*

torque value drops below the required minimum of 9 Nm (Sample No. 16 and 17).

Following the one factor change at a time strategy, we came to a good solution with parameters: 45 % laser power, −0.75 mm defocus, −0.2 mm welding position.

4. Conclusions

Focus spot offsets only show proper results at 45% of laser power, other offsets gave the highest machine capability index when different laser power was used. To verify this point, we performed an experiment using the above offsets at 60 % laser power, resulting Cpk of 0.77 (as opposed to 4.69).

The disadvantage of this strategy is that we do not know the interactions of the factors, but from the results we have selected the ranges within which the factor experiments are worth performing: 45–70 % laser power, defocus 0.75–(−1.25) mm, welding position 0.00–(−0.3) mm. We also want to know the effect of speed, so we have included it in the range of 30-50 mm/s.

The breaking torque charts show more than just the change of the values. It also can be observed from the laser power diagram that the average breaking torque index of Sample No. 1 and Sample No. 5 differs only by 0.1 Nm and there is also a difference of 0.1 in the machine capability index. From this it can be concluded that the two seams have same load capacity, but this can be determined by further detailed investigations, since there was a significant difference in the laser power, i.e. due to different heat input, the weld width, hardness value and microstructure should be examined in addition.

The optimum laser power can be determined at 60 %, as it has the highest average breaking torque value, lowest standard deviation, highest Cpk value, but the load capacity of joint does not deteriorate as the power changes. This is also shown in **Figure 5.** the defocus does not affect the breaking torque value within the tube wall thickness (0–(−2) mm). The welding position has the greatest effect on the breaking torque value, the change of this parameter sharply deteriorates the joint quality if the change is greater than ±0.1 mm.

We can also observe the so-called „Outliers" in **Figures 4.** and **5.** These values are farther from the mean value, but above the specified value (e.g., Sample No. 10, segment Nr. 3 had a 11.7 Nm, segment Nr. 4 had a 17.3 Nm). Visual inspection of the seams after welding did not show any surface damage, leakage to the surface, welding defects. More detailed microscopic examination (e.g. optical light microscopy or scanning electron microscopy) could determine the difference between the seams.

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