Laser beam cutting and welding of coronary stents

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Abstract

Coronary stents are thin-walled and mesh-structured metallic implants, which are made generally by laser beam cutting of high-precision tubes of 90-120 micrometer thickness. The tube material can be 316L stainless steel or L605 type cobalt-chromium alloy. The paper present how laser settings influence geometry and surface quality of the kerf and residual stresses, which play very important role in the precision of stent strut homogeneity.

Hungarian Tentaur stent was developed 15 years ago. This coil stent made of 145 micrometers thick stainless steel wire contains 9-25 joints produced by electric resistance projection welding. Developments were bringing out for increasing flexibility of Tentaur stent, and a new design and a new tech-nology was elaborated, which's based on laser beam mi-crowelding. TentaFlex stent also is constructed from austenitic stainless steel wire, but it does not contain any wire-crossing joint, because stent struts are configured from sinusoidal helix. Stent contains only two welded joints at its ends. Laser welding experiences of these joints are presented in the paper. A Trumpf PowerWeld Nd:YAG laser work station was used for welding, and after optimization of laser settings joints can't produces from only one side of the coiled stent.

Introduction

The main production method for small work pieces is laser cutting [1,2]. Nowadays the most commonly used laser for thin Work piece cutting is Nd:YAG laser with 1064 nm wave-length. It has got different configurations: either with conventional flash lamp excitation, (for example Lasag KLS 246) or with lased diode excitation having better efficiency, or with Q-switch: capable for emitting high-energy pulses. Thawarimade a full analysis of the higher power pulsed Nd:YAG laser cutting of Ni-base superalloys [3,4].

Beside a laser system, a positioning system is necessary for small work piece fabrication. This positioning system clamps the workpiece and moves it relatively to the laser spot forming the structure of the workpiece [5]. The positioning system for tube fabrication ensures a translation, a rotation and an adjustment of the mutual position of the work piece and the laser spot. Minvasive Ltd., based on Aerotech parts developed the positioning system used for the experiments.

Laser cutting experiments

Objective: examine the effect of different cutting speed with earlier optimized pulse frequency-pulse energy combination in order to use the appropriate cutting speed settings in stent fabrication. Applied laser system: LASAG KLS 246 pulsed Nd:YAG with 15 W average power. Work piece positioning system: produced by Aerotec Ltd., allowing two perpendicular translations in horizontal plane plus rotation around horizontal axis controlled with Cutcontrol program developed by the Minvasive Ltd. [6].

TABLE 1: CHEMICAL COMPOSITION OF AISI 304L AUSTENITIC STAINLESS STEEL

C	0,07
Cr	18,31
Ni	10,06
Mn	1,76
Si	0,99

The applied material was AISI 304L austenitic stainless steel tube with 1,800 mm diameter and 0.120 mm thickness. The chemical composition of the material can be seen in Table 1.

The stainless steel tubes were cut at axial direction 4 mm long, and then in 200 ° region the mantle were cut perpendicular to the axis, then tubes were cut again at axial direction 4 mm long at the direction of the end of the tube removing a part of the mantle (Fig 1).

Table 2 shows the laser processing parameters used for this experiment. The laser cutting experiment was made with the aid of oxygen gas. The pressure of oxygen was 5×105 Pa. The exothermic reaction of oxygen and the material made the cut-ting faster [7-9].

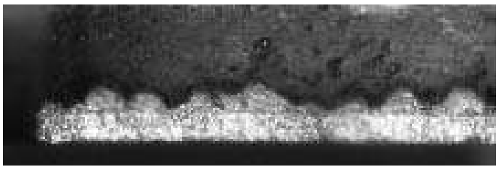

Figure 1: Cutting speed = 9 mm/s, cutting edge

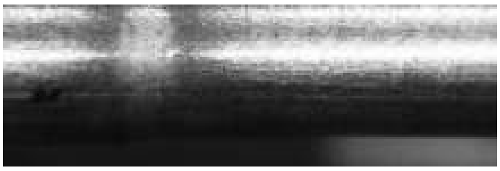

Figure 2: Cutting speed = 9 mm/s; outer surface of the tube

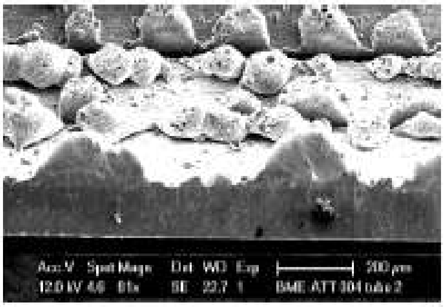

Figure 3. Dross height equals the wall thickness, SEM picture

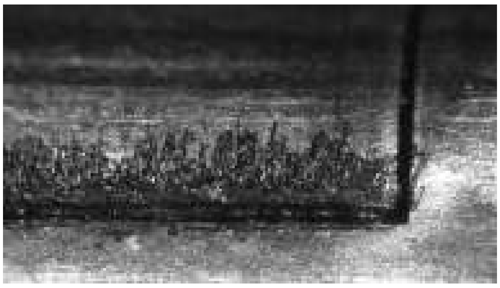

Figure 4: Cutting speed = 21 mm/s, the laser could not cut trough the material

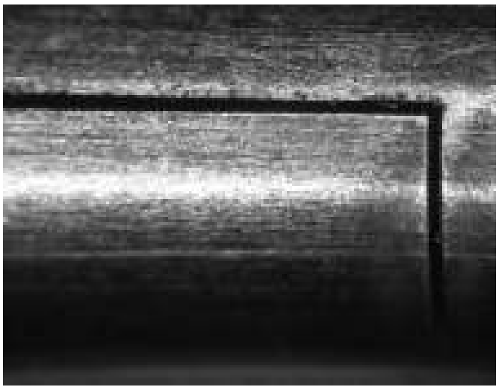

Figure 5: Cutting speed = 21 mm/s, in this part of the cut the laser cut trough the material

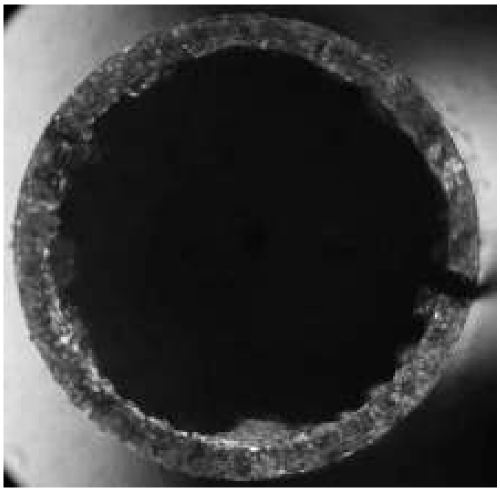

Figure 6: Dross adherence at the cropping of the tube

TABLE 2: LASER PROCESSING PARAMETERS

	Laser settings
Pulse frequency	1500 Hz
Average power	8,7 W
Pulse width	0,02 ms
Pulse energy	5. 8 mJ
Processing speed	9, 15, 18, 21 mm/s
Focus position	At the surface of the tube

Laser cutting results

The tube cutting with 9 and 15 mm/s speed was successful. Fig. 1 shows the dross adherence at the cutting edge and the spattering at the inner wall of the tube. At the beginning of the cut there is no dross adherence, at the end of the cut there is a noticeable dross adherence. Fig. 2 shows the opposite side of the mantle cutting perpendicular to the axis; the laser beam caused discoloration can be observed, changing the properties of the base material. This effect caused by the relatively high energy pulses and needs further investigation: what will happen when we cut these heat-treated areas?

Using 18 and 21 mm/s cutting speed, the laser could not cut trough the material at the beginning of the cutting line (Fig. 4). This problem caused by the dross adherence at the crop of the tube. The height of the dross can be the same as the wall thickness of the tube, and it is difficult to cut the wall and the dross together (Fig. 3 and 6).

Probably one pulse could not cut the wall of the tube trough: we need large spot overlap for cutting. As at the beginning of the cut line the laser could not cut the material: the oxygen assist gas unable to blow out the molten material to the direction of the inner surface of the tube it is spattering back to the outer surface (Fig. 4).

It's taken a relatively long time, long kerf line to cut through the material (Fig. 5). It is interesting, that when the laser be-gins to cut through the material there is no problem with the cutting the same dross adherence at the end of the tube. This dross-caused problem occurs only at the beginning of the cut.

Since dross adherence plays key role in the beginning of the cut it would be necessary to elaborate laser settings causing lower dross adherence [10,11]. These settings will allow cut-ting the material faster.

There are two other factors affecting these no-cut problems: the form-failure of the tube and misalignments of the tube during cutting. Since our large beam expander settings causing shorter Rayleigh-length small misalignments and form-failures can make the laser out-of focus. It is worth to analyse this problems in the future.

Development of ultra-flexible stents

Developing ultra-flexible stents from tube and wire, optimising the functional attributes of them and specifying the clinical attributes of ultra-flexible uncoated stents bulk large in the project. Laser cutting gives us an adequate technology to pro-duce ultra-flexible implants in a short time; the cutting period is depending on the length of the stent and the complexity of the design. The shape of the kerf depends on the material of the implant. An CAD-software (ProEngineer) is used for de-signing (Fig. 7), examining and for optimising the functional attributes of ultra-flexible uncoated stents (for example: Solid Edge, CAD, FEM software).

Finite element method (FEM) can help identify some valuable mechanical characteristics of stents, arteries, and their interactions, which cannot be easily obtained by routine methods. Elaborating posterior surface treatment technologies is decisive as well, because it changes the kerf width and the wall thickness of the stents.

The testing of the properties of coated and uncoated stents, to be carried out under realistic circumstances, and the expensive pre-clinical and clinical tests which are inevitable when re-questing approval from the authorities will be implemented mostly in haemodynamic laboratories. The tasks comprise experiments of sterilizing and mounting onto balloons as well as determination of radio-opacity and measurement of balloon expansion properties.

Developing the technology of mounting onto a balloon catheter, optimised to profile size and flexibility is an important subtask of this development. All partners participate in this phase of the project and will select and develop the most suit-able balloon catheter and determines the optimal pressure values at balloon expanding. The experts assess the strengths and weaknesses of the new domestic stents' clinical application with comparison (benchmarking) tests.

Within the frameworks of the development of new production techniques based on laser technology, laser beam welding-based manufacturing of stents produced of wire (see Fig. 8-13, and Table 3.), for AISI 316L steel are researched.

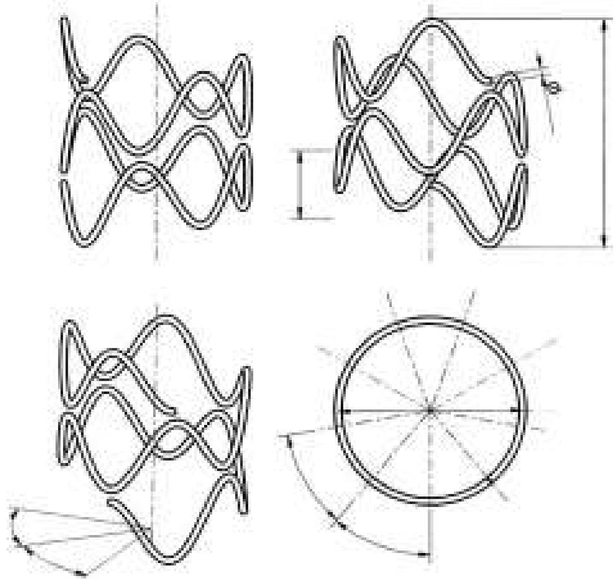

Figure 7: Ultra-flexible TentaFlex Stent

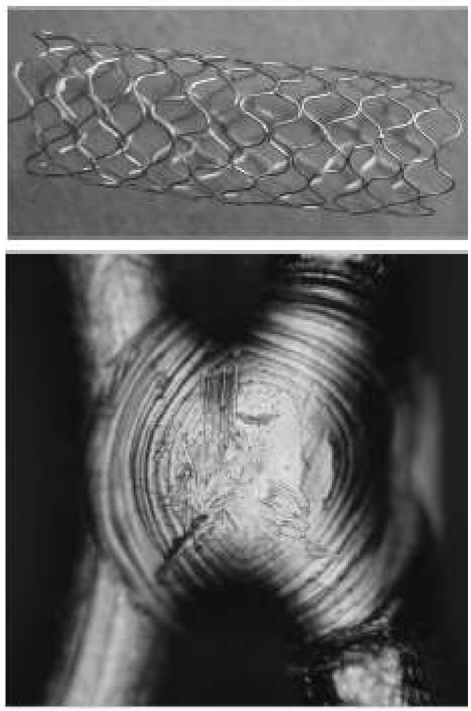

Figure 8: Prototype of laser welded ultra-flexible stent (untreated surface)

TABLE 3: ONE-SIDED LASER SPOT WELDING PARAMETERS

Spot size (mm)	0,4
Peak power (kW)	0,34
Pulse time (ms)	2,4
Shots (db/cycle)	2
Frequency (kHz)	2,5
Energy (J)	0,8
Average power (W)	2

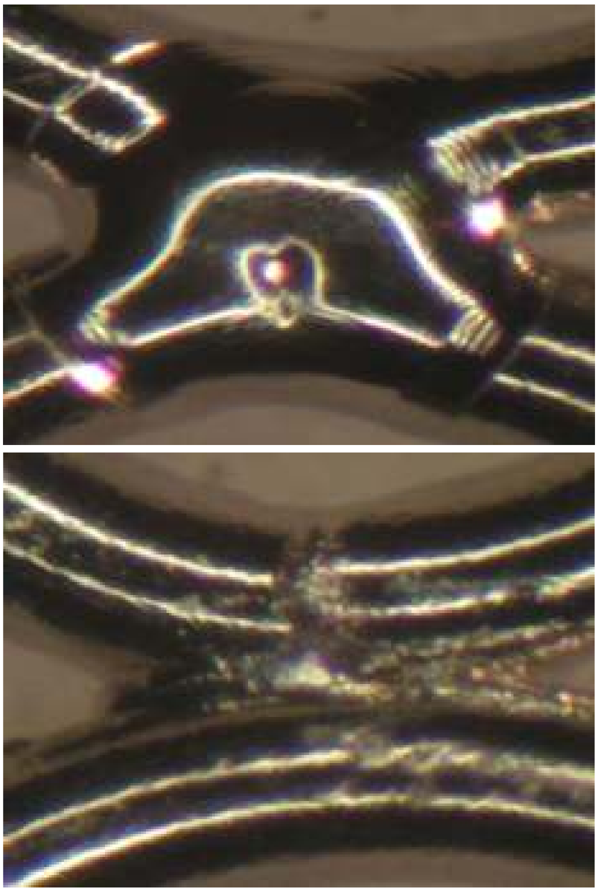

Figure 9: One-sided welded joint

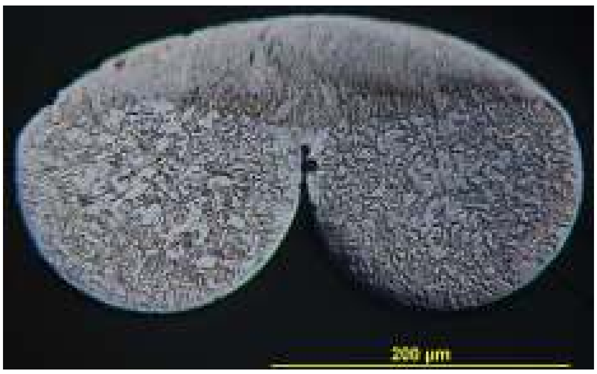

Figure 10: Cross section of a one-sided welded joint

Figure 11: Producing and balloon expansion steps

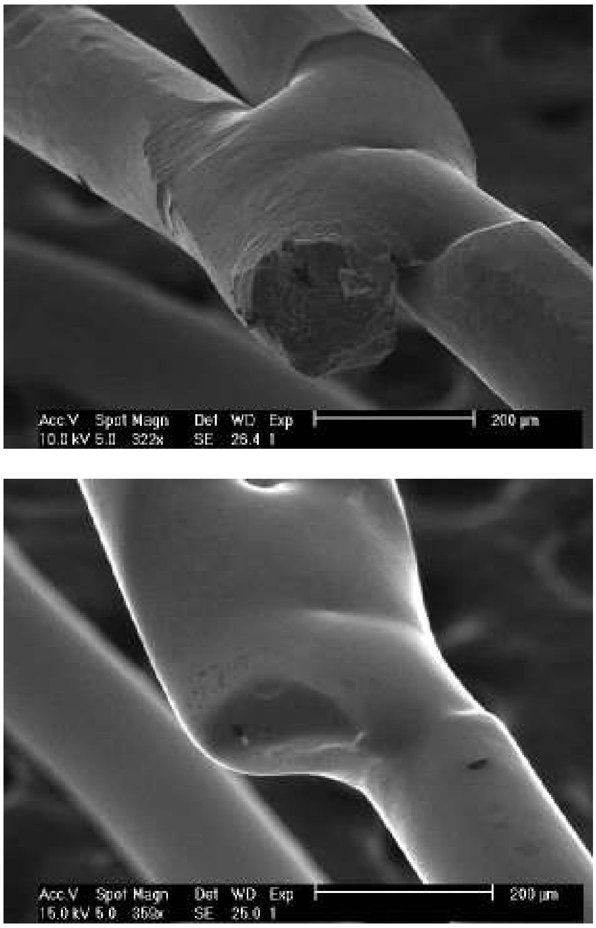

Figure 12: Welded joint of the TentaFlex stent before and after electropolishing

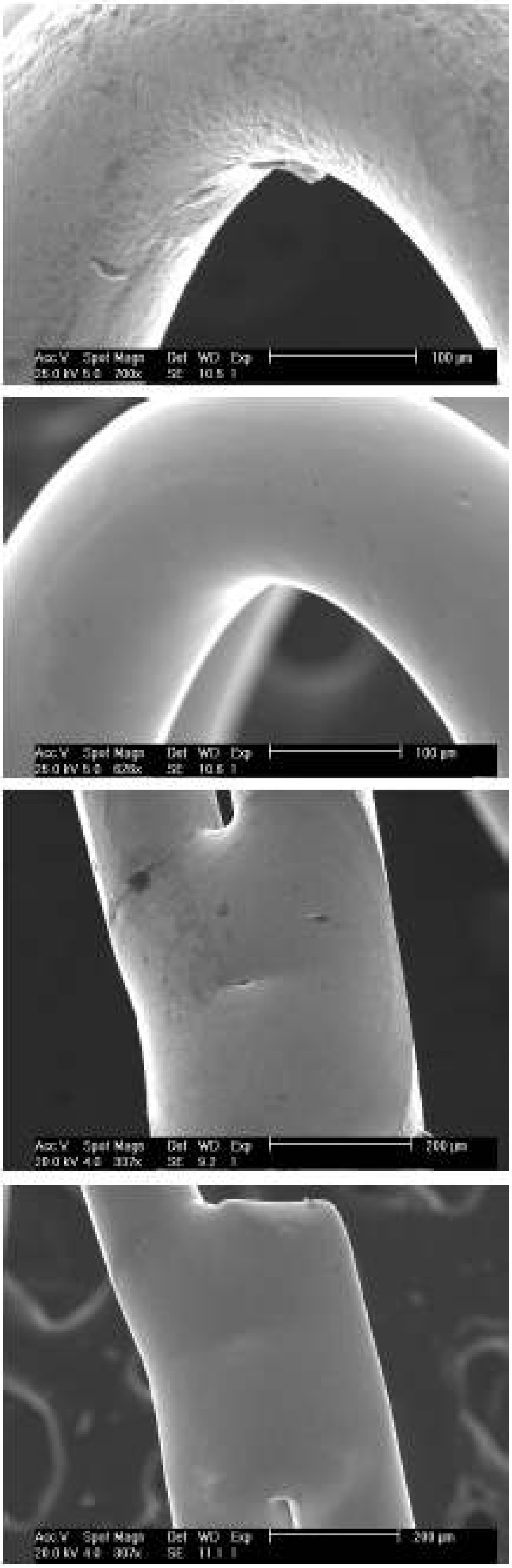

Figure 13: Different parts of the TentaFlex stent before and after electropolishing

Conclusion

The effects of the laser cutting speed parameters of precision stainless steel tube were analysed. The following consequences can be drawn:

Reliable cuts can be made with 9 and 15 mm/s settings. The cut with 18 and 21 mm/s speed was not successful because of the dross adherence caused by the laser cropping of the tube. Since dross adherence plays key role in the beginning of the cut it would be necessary to elaborate laser settings causing lower dross adherence [3]. These settings will allow cutting the material faster. The form-failure of the tube and misalignments has to be analysed.

Acknowledgements

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