PROCESS PARAMETERS DEVELOPMENT FOR COPPER THIN WALLS MANUFACTURING VIA 3D PRINTING

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Abstrakt

The subject of this work is the processing of copper alloy by the method of Selective Laser Melting (SLM). It is important determine the process parameters of laser entering the building process of very thin walls and to verify their impact on the stability of the building process. The copper alloy Cu7.2Ni1.8Si1Cr is processed with application focused on thin-walled elements in construction of heat exchangers and coolers. This paper deals with the preparation, construction and evaluation of experimental samples containing separate walls and their groups placed perpendicularly and at an angle of 45 degrees to the platform. The focus of this work is on the quality of the created surfaces and dimensions of the walls. Quality evaluation is performed by measuring the wall thickness and surface roughness measurement.

Key words

Thin wall, Copper alloy, SLM, Copper, Cu7.2Ni1.8Si1Cr, Surface quality

1 Introduction

Selective Laser Melting (SLM) is an additive manufacturing technology that uses the metal powder melting process by delivering local heat. As a source of energy to produce the heat, a high intensity laser is used. The process of SLM involves a large number of process settings, the combination of which has a major impact on the resulting quality and shape of the manufactured component. Copper alloys are widely used primarily for their high electrical thermal and conductivity and good mechanical properties. Excellent thermal conductivity predisposes copper alloys for their use in the power industry and the production of high performance heat exchangers and coolers. To ensure the high efficiency of these coolers and heat exchangers, an attempt is made to maximize the exchange area between the cooling and the cooled media, which is achieved in particular by the high concentration of thin slab in a small volume. For this purpose, it is necessary to optimize the construction process aimed at thin-walled elements.

The first attempt to process copper alloys via SLM was created in 2006 when W. Wu, Y. Yang, and Y. Huang were dealing with the Cu8Sn6.5P1Ni alloy (1). The powder was treated with DiMetal-240 with a laser power 90 W and a diameter of spot size 100 μm. The powder layer 320 μm thick was scanned at a speed of 500 to 1000 mm/s (recoating). The authors reached the final relative density of bulk samples 95%.

D. Q. Zhang, Z.H. Liu, S.L., et al., used copper alloy Hovadur K220 which chemical composition was 2.4% Ni, 0.7% Si, 0.4 Cr and 96.5% Cu (2). They used SLM 250HL equipped with a 400W laser with a spot size 80 μm. The metal powder was formed by Gas atomization with a particle diameter of 20-63 μm. The authors achieved a volume density 99.9% with process parameters 370 W, hatch distance 90 μm, scanning speed 530 mm/s and a thickness of the powder layer 30 μm.

Cu-Cr-Zr-Ti alloy with a chemical composition of 0.5-0.7% Cr, 0.02-0.05% Zr, 0.02-0.05% Ti and Cu residue was discussed by A. Popovich, V. Sufiiarov, I. Polozov, E. Borisov, D. Masaylo, A. Orlov (3). The material was processed by SLM 280HL with a 400 W laser. The highest relative density of the 97.9% volumes was created with 400 W, scanning speed 400 mm/s, hatch distance 100 μm and powder layer thikness 50 μm.

Lykov P.A., Safonov E.V. and Akhmedianov A.M. processed pure copper on the SINTERSTATION® Pro DM125 SLM CO2 laser system with a power of 200 W and a beam diameter of 35 μm (4). The powder was formed by gas atomization with an average particle size of 32.52 ± 19.86 μm. The work was focused on volume samples (cube tests 10x10x5 mm), when the highest density of 88.1% reached with laser power 200 W, scanning speed 100 mm/s and hatch distance 50 μm. The powder layer thikness was 50 μm

2 Materials and Methods

2.1 Experimental equipment

In the work was used 3D printer from the German company SLM Solution GmbH, type SLM 280 HL equipped with a 400 W YLR laser with a Gaussian beam intensity distribution. The laser spot size was 82 μm and a maximum scanning speed 15 m/s. During the experiments an inert atmosphere of nitrogen was used.

2.2 Copper powder

The powder used was purchased from Sandvik Osprey in a 20 kg package with a Cu7.2Ni1.8Si1Cr chemical composition and an average particle size of 22 μm (fig.1, tab.1). Based on the SEM analysis, the powder morphology was evaluated (5). The particles contained mainly a spherical shape with a large variability in the size dimension (fig.2). A layer of powder with a thickness of 50 μm was used in the work.

Tab. 1 Distribution of particle size

Distribution of particle size	
D10%	11,1 μm
D50%	22,9 μm
D90%	38,6 μm

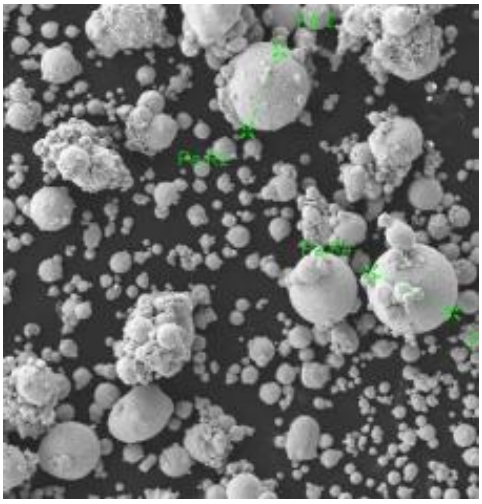

Figure 2 Morfology of used copper powder (5)

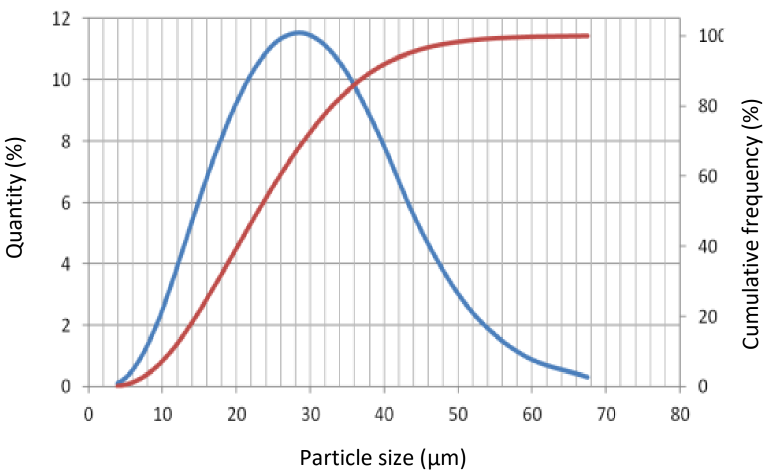

Figure 1 Distribution of particle size of used copper powder (5)

2.3 Postup riešenia práce

The procedure for the solution of the work consisted in the production of 4 types of samples. All samples were analyzed after build (fig. 3)

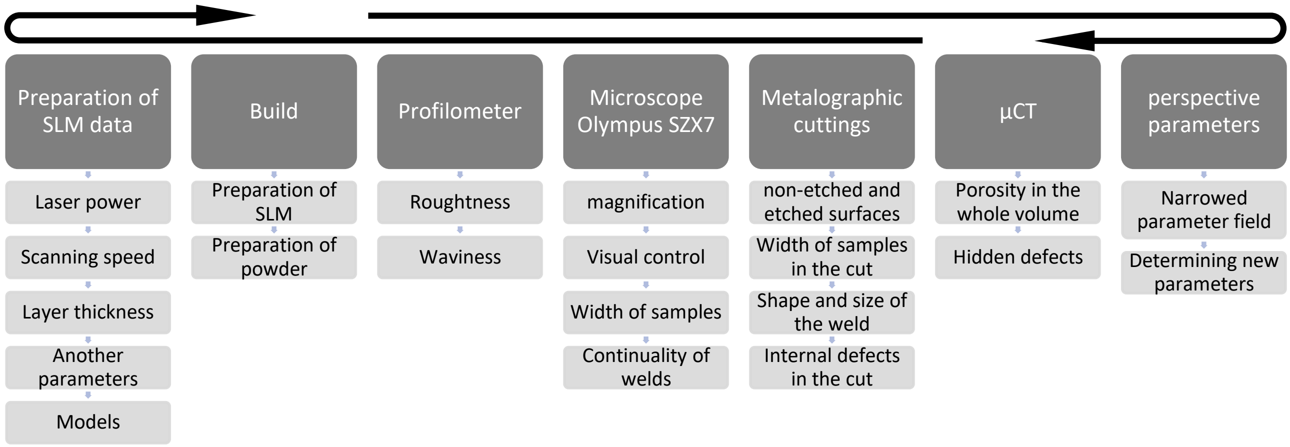

Figure 3 Analysis cycle

2.4 Analysis

Metallographic cuttings were created on some samples. EpoThinTM2 was used as the casting material, which was placed in a vacuum for 30-40 minutes at 10 mba. The cuts were created on the Leco GPX300 metallographic grinding machine in a conventional way using wet grinding and mechanical polishing using diamond pastes. Etching at the boundary of the welds was done with $FeCl_3$, HCl, ethanol (1:18:58). Etched surfaces were evaluated using the Olympus SZX7 microscope, which was equipped with the Canon EOS 1200D digital camera. The evaluation of all cuts was carried out using QuickPHOTO MICRO 3.1. The surface roughness evaluation was carried out on an area of 2.2x1.6 mm with Bruker Contour GT-X8 and subsequent processing of the data by Vision64. A standard ultrasonic cleaner was used to remove excess metal powder. Computed tomography analysis was performed on a GE phoenix device x L 240. The Vickers hardness was measured by the Leco LM 247 AT.

2.5 Experiments

In this work, 4 types of samples were created in multiple experiments, whereby the process parameters were analyzed. All specimens were rotated at the construction platform by 95 degrees to the blade of the coating device. Before the construction of the metal powder was dried at 70 ° C for at least 4 hours. Subsequently, it was moved forward to the recoater, which was placed in a building chamber with an inert atmosphere of nitrogen. All samples were built on a platform with dimensions of 98x98 mm made from alloy AMPCOLOY® 944 and heated to 100˚C.

2.5.1 Test of single perpendicular walls – 100 ks

The first types of samples created at work were created with contour only. Internal hatching and other types of hatch have been disabled. Samples were prepared using 350 and 400 W power lasers. The scanning speed ranged from 800 to 1000 mm/s (50 mm/s) and 1100 to 1700 mm/s (150 mm/s). The walls were formed by 2 opposite laser trajectories distance 1, 50, 100, 150, 200 µm. The trajectory distance was created by offsetting the laser trajectory from the model borders by 25µm. The dimensions of the CAD model were 10x10x (50/100/150/200/250).

2.5.2 Repetation of build of the single perpendicular walls

The next section was built 2x12 separate vertical walls. The process parameters and laser trajectory distance were determined based on the results of 1st experiment. Reducing the number of samples focused on the area of perspective process parameters (tab.2).

Tab. 2 Perspective process parameters

Number of parameter	Laser Power (W)	Scanning speed (mm/s)	Hatch distance (μm)
1	400	900	1
2	400	1700	1
3	350	1700	1
4	400	850	1
5	400	1250	1
6	350	1550	1
7	400	800	1
8	400	1100	1
9	350	850	50
10	350	800	100
11	400	850	150
12	400	800	100

2.5.3 Test of a group of 20 perpendicular walls

The next test was prepared to verify 4 of the 12 process parameter groups (par. groups 1, 6, 7, 9) on sets of 20 vertical walls separated by 100 μm. The walls are built on the support volume prepared by laser power 400 W, scanning speed 1100 mm/s and a hatch distance 90 microns. From each set of process parameters, 4 samples (together 16) were built in the corner areas of the building platform spaced 50 mm apart. The aim was to verify the impact of sample locations on the base platform.

2.5.4 Test of a group of 10 perpendicular walls

The following samples were made to work a modified set of 10 vertical walls. These samples included 10 vertical walls spaced 400 microns. As in the previous test, all samples were 4x each set of process parameters (48 in total) in corner areas on two platforms.

2.5.5 Test of single walls at an angle 45˚

In the work was built 12 samples angled 45˚ to the building platform. The same processing parameters were used for their construction as in tab. The difference occurs only at the laser beam trajectory distance (laser trajectory compensation from the CAD model boundary), which is increased due to a change in the construction angle, thereby increasing the thickness of the sample in the cut.

2.5.6 Test of groups of 6 walls at an angle 45˚

The next experiment contained sets of 6 walls built at an angle of 45 degrees to the building platform, which were 400 μm apart. Specifically, 12 samples were built using 12 groups of process parameters from the tab.1.

2.5.7 Test of strategy down skin

The latest test was focused on verifying the impact of the down skin construction strategy. In this part, 9 combinations of the down skin parameter, which were applied with 200, 300, 400 W, scanning speeds of 600, 900 and 1300 mm / s, were designed. The down skin location was calculated from the previous layer (Layer reference = 1).

3 Results and discussion

3.1 Test of single perpendicular walls – 100 ks

100 walls were made, each created by a different set of process parameters. From the first sight of the samples after the build was visible large variety of quality single wall. Three groups of samples were visible when looking at the last weld by optical microscope. The first group contained samples in which a continuous weld was visible. These quality was most frequent in samples built at lower speeds (800-900 mm / s) and distance of lasers trajectories 1 and 50 µm and both laser performances. At speeds above 1000 mm/s at both power and laser trajectory distances of 1 and 50 µm phenomenon, when the last 1-2 mm of the samples have a bifurcation of the wall and its significant expansion. This phenomenon can be seen in fig.5. All the other samples contained poor quality welds. The roughness parameter was evaluated on all surfaces where the values of 9.1 - 21.9 µm were reached. After determining the roughness of the surface, metallographic cuttings were created to measure the widths of individual walls. The value was average of two measured values. Just for comparison the measured wall widths by metallographic cuts were compared with the measured values viewed from above. Between the values, an average deviation of 77µm was found. It is possible to see in the fig.4 a trend describing the influence of the speed increase on the width of the walls when the thickness decreases with increasing speed. After measuring the width, the individual surfaces were etched inorder to see welds in the cut. Two groups were visible, the first containing a regular and symmetrical welds. The second group was the opposite, poor and distorted welds On the basis of the obtained data, a narrow range of samples was selected, combining the best achieved results (good surface roughness, continuous top welding and symmetrical jar). Narrower field of 12 sets of parameters is shown in tab.1. On the basis of the obtained data, a narrow range of samples was selected, combining the best achieved results (good surface roughness, continuous top welding and symmetrical welds). Narrower field of 12 sets of parameters is shown in tab.1.

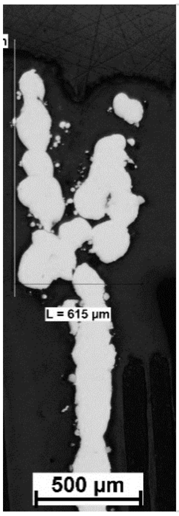

Figure 5 Sample defect

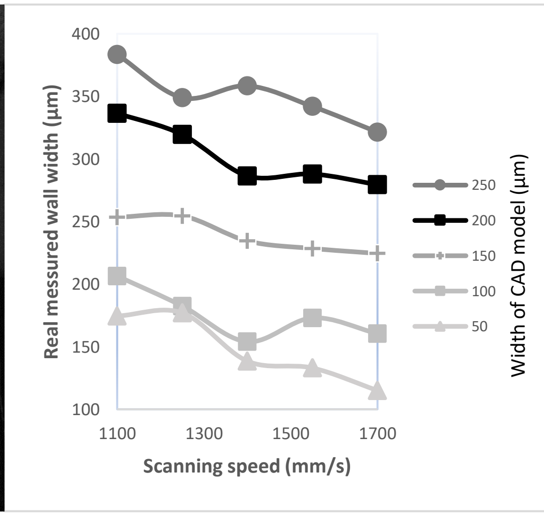

Figure 4 Dependence of the measured width of the wall at the scanning speed, Lp 400W

3.2 Repetation of build of the single perpendicular walls

To verify repeatability, separate perpendicular walls were rebuilt, which were built up by the narrowed field of the process parameter groups (tab.1). Almost all samples after the removal from the building chamber have collapsed. Successfully, only samples were generated by the groups of process parameters 11 and 12. The same results were obtained at the next repetition of the experiment, which included the same samples and the same set of process parameters.

3.3 Test of a group of 20 perpendicular walls

The following experiment consisted of building sets of 20 thin, perpendicular walls. The distance of each wall was 100 μm. 16 samples were constructed by 4 groups of process parameters. Upon a detailed top view of the last weld, it was possible to see different results in the samples built up by the same set of process parameters. Figure 6 shows samples of Process Parameters 1 (Lp = 400 W, Ss = 900 mm / s, Hd = 1 μm). Samples placed at the inlet of the inert gas into the building chamber (right, position 2, 4) show a better quality of the last weld compared to the samples located on the side of its exit from the chamber (left, position 1, 3). Looking at the sample side is visible in several places linking walls (fig.7). This fact was confirmed by metallographic sections, when the measured width of the walls at the entrance of gas is less in comparison with the opposite side. the surface roughness evaluation also showed a dependence on the position. Samples placed at the inlet gas inlet reached a higher roughness of approximately 4-8 μm (fig.8).

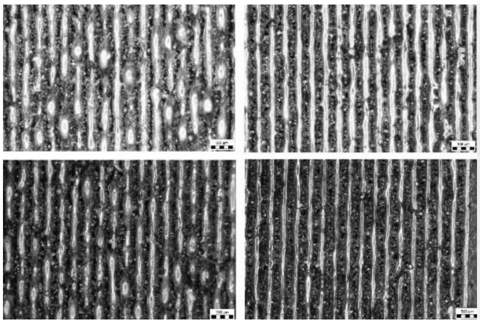

Figure 6 Top view of samples built with same parameters at different places on platform

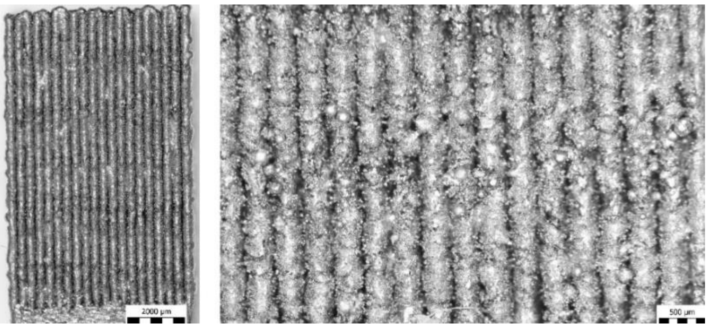

Figure 7 Side view with defects

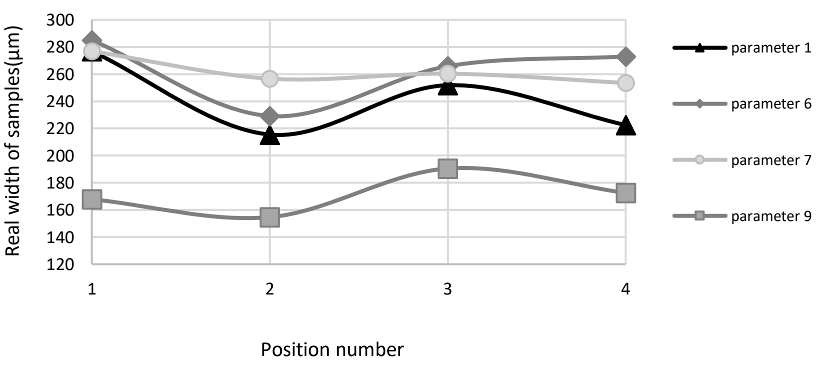

Figure 8 Real widht of samples ad diferent location on platform

3.4 Test of a group of 10 perpendicular walls

In this part, modified samples from the previous experiment were built, when the distance between the individual walls was increased to 400 μm (fig.9). As a result of the enlargement of the gap between the walls there was a significant improvement of the quality of the resulting walls, there was no interconnection. At the top view, high quality shots were visible in almost all samples. With the minimum number of samples, there was a small connection at the last millimeter of the building. On some samples, wall-to-wall disturbances were visible in approximately half of the building. These results were confirmed by metallographic specimens. This category included samples comprised of process parameter groups 2, 3, 5, 6, 8 (tab.1). During their construction, the walls moved from the center to the sides (fig.9 left). At some point, the separation of the newly created layers, which were partly attached to the samples, or were built into pure metal powder. This phenomenon may be caused by the edge effect that has begun to appear on these samples. In all samples, more powder was melted at the ends of the walls, resulting in a slight lift of the wall corners upward, which could be deflected sideways at the passage of the blade. The second set of samples was constructed by a set of process parameters 9, 10, 11, 12. This phenomenon may be caused by the edge effect that has begun to appear on these samples. In all samples, more powder was deposited at the ends of the walls, resulting in a slight lift of the wall corners upwards, which had been deflected sideways at the passage of the blade. The second set of samples was built by a set of process parameters 9, 10, 11, 12. These samples contained a good amount of pore-free volume, but on the surface, appeared larger amount of sinter-fused powder (fig.9 middle). The last set of samples, built with parameters 1, 4, 7, 9, reached the highest quality and there was no coagulated powder on the surface (fig.9 right). With these samples, a phenomenon occurred when samples with the same set of process parameters at different platform positions were subject to regular constriction at the same height. For the other parameter groups, this phenomenon appeared at different heights, but they were the same for one parameter group. In the surface roughness evaluation, the surface roughness of the inert gas in the chamber was approximately 8-15 μm higher compared to the opposite side in the samples of the process parameters 5, 7, 9, 10, 11. The roughness values range from 9.2 to 29.5 μm.

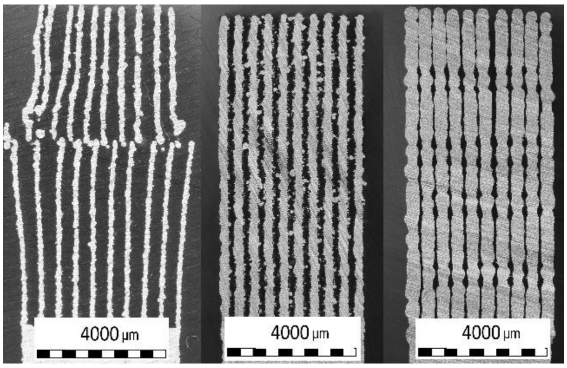

Figure 9 3 types of quality of built samples (left: breaked walls, middle: bad surface, right: the best quality

The tab.3 displays the process parameters that have achieved the best results, based on previous analyzes.

Tab. 3 The best results parameters

č. parametru	lp (W)	ss (mm/s)	hd (μm)	šírka (μm)	ØSa (μm)
1	400	900	1	300-400	15,7
4	400	850	1	230-280	15,6
7	400	800	1	300-400	15,9
9	350	850	50	260-300	17,8

3.5 Test of single walls at an angle 45˚

The impact of the change in angle was tested on samples that clawed 45˚ with the platform. By analyzing the last weld, samples were divided into 2 groups. The first one contained the ballage effect affected by the splitting of this weld into small balls, the process parameter groups 2, 3, 6. The other samples contained high quality deflections without defects. Looking at the cuts, a significant surface deterioration (fig.10) was visible on all samples. When increasing the construction angle, a stairway effect occurs based on the principle of SLM technology. All 12 separate walls were expected to experience significant deterioration in all directions. The surface of the samples was fractured with a high defect content, nascent powder, and pore volume.

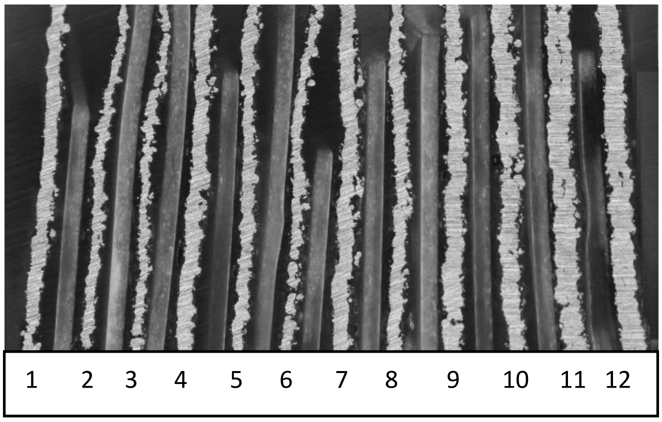

Figure 10 Metallographic cuts of all 12 single walls

3.6 Test of groups of 6 walls at an angle 45˚

Other samples contained 6 walls spaced 400 μm apart at an angle of 45 °. In all samples were created continuously welds (fig.11). The occurrence of the phenomenon described in Chapter 4.1.3 was observed on the 6 samples set up by the process parameters group 2, 4, 7, 8, 9, 10 which, on sloping walls, caused a smaller swing of the samples to the side. In parameter group no. 9, this effect was so noticeable that the individual walls were interconnected. For samples 3 and 6, the walls were deformed and then connected to the final part of the building. Others created samples contained a smaller amount of sinter-fused powder without major defects. The width of the walls ranged from 265 to 477 microns (fig.12), and surface roughness values on the lower (upper) side of the samples were from 28.1 to 44.1 (12.8 to 25.6) (fig.13)

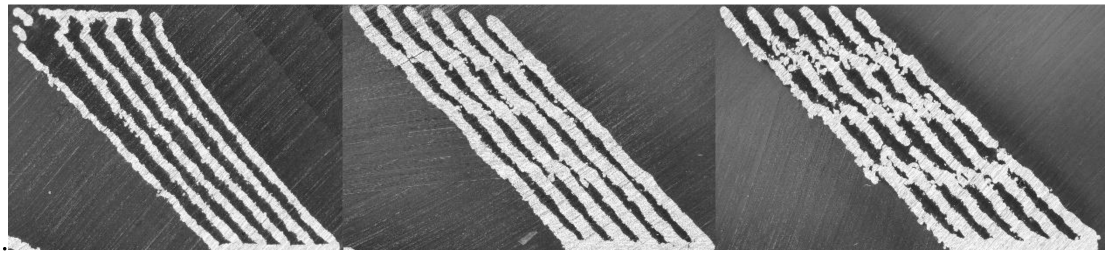

Figure 11 3 Types of defects

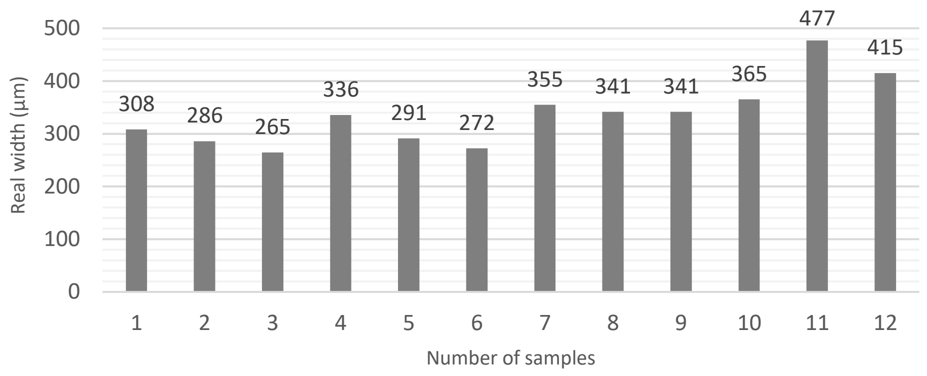

Figure 12 Average values of widths sets of walls at an angle of 45˚

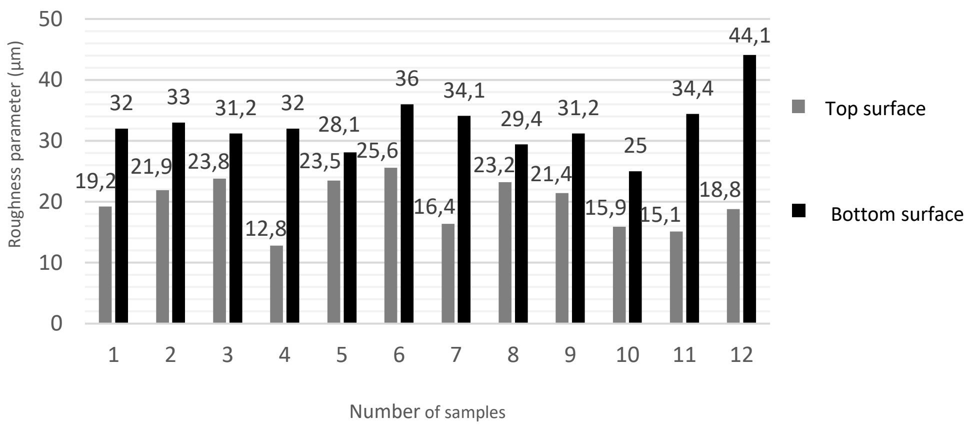

Figure 13 Comparison of the roughness parameter of sets of 6 walls at an angle of 45˚ top / bottom

3.7 Test of strategy down skin

The work has been tested for the impact of the down-skin strategy. There are 9 sets of thin walls spaced apart from each other 400 µm. Parameter down skin was applied to samples based on the process parameter group 1 (Lp = 400 W, Ss = 900 mm / s, Hd = 1 µm). The results of the experiment showed the negative effect of this strategy on the final quality of the walls. Based on the measured widths, the laser effect performance trend was visible. With an increase in laser power, an increase in the wall thickness value has occurred. This trend is due to an increase in the amount of energy supplied to the melting pool when a larger amount of powder is melted. Also, in all samples, the surface quality deteriorated mainly on the underside with an average of 10 to 20 µm as compared to the samples without down skin.

4 Conclusion

The aim of the work was to find a suitable set of process parameters useful for Cu7,2Ni1,8Si1Cr alloy processing with focus on thin-walled application. Based on the results, the ability to process the selected alloy by slm was confirmed. The best surface roughness results of 14-15 µm were created on samples set up by the Process Parameter Groups 1 (tab.1). Laser power 400 W, scanning speed 900 mm / s and laser trajectory distance 1 µm at a layer thickness of 50 µm powder applied. (higher wall concentration). Wall thicknesses created by these parameters reached values of 300-360 µm. The influence of the position of the samples on the building platform was also proved. Samples placed closer to the inlet gas in the chamber reached smaller thicknesses of 50-60 µm. For this group of parameters the influence of the position on the resulting roughness of the surface was not proved. The µCt analysis showed a relative density of 99.97% when the majority of the pore distribution was located in the corner areas of the walls where the edge effect occurred. In the case of walls built at an angle of 45 ° there was a deterioration in surface roughness. The bottom has a value of 32 µm and a top of 19.2 µm. The average width of these walls varied approximately to the same value as the perpendicular walls, namely 308 µm. The use of the down skin construction strategy has aggravated all the results (wall size, roughness, wall quality)

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