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# EXAMINATION OF MATERIAL MANUFACTURED BY DIRECT METAL LASER SINTERING (DMLS)

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This article is concerned with assessing microstructural properties of metal component manufactured by additive DMLS technology. Two series of samples were assessed. The first one was manufactured without heat treatment. Samples in the second series were treated with heat in order to assess increase in hardness and influence on modification of microstructure. Subsequently, values of hardness were measured by Vickers Hardness Test and modification of microstructure was observed by optical microscope. Evaluations were carried out in three planes in order to assess the differences in layering of material during its processing. Differences in values of hardness and microstructural components were discovered by examination of changes in three planes.

*Key words:* direct metal laser sintering, heat treatment, hardness, microstructure

## INTRODUCTION

Direct Metal Laser Sintering (DMLS) was developed jointly by Rapid Product Innovations (RPI) and EOS GmbH, starting in 1994, as the first commercial rapid prototyping method to produce metal parts in a single process. With DMLS, metal powder (20 micron diameter), free of binder or fluxing agent, is completely melted by the scanning of a high power laser beam to build the part with properties of the original material. [1] Eliminating the polymer binder avoids the burn-off and infiltration steps, and produces a 95 % dense steel part compared to roughly 70 % density with Selective Laser Sintering (SLS). [2]

An additional benefit of the DMLS process compared to SLS is higher detail resolution due to the use of thinner layers, enabled by a smaller powder diameter. This capability allows for more intricate part shapes. [3,4] Material options that are currently offered include alloy steel, stainless steel, tool steel, aluminum, bronze, cobalt-chrome, and titanium. In addition to functional prototypes, DMLS is often used to produce rapid tooling, medical implants, and aerospace parts for high heat applications. [5,6].

## EXPERIMENTAL PROCEDURE

Samples were manufactured by 3D printer EOSINT M280 for the additive manufacturing of metal products directly from CAD data.

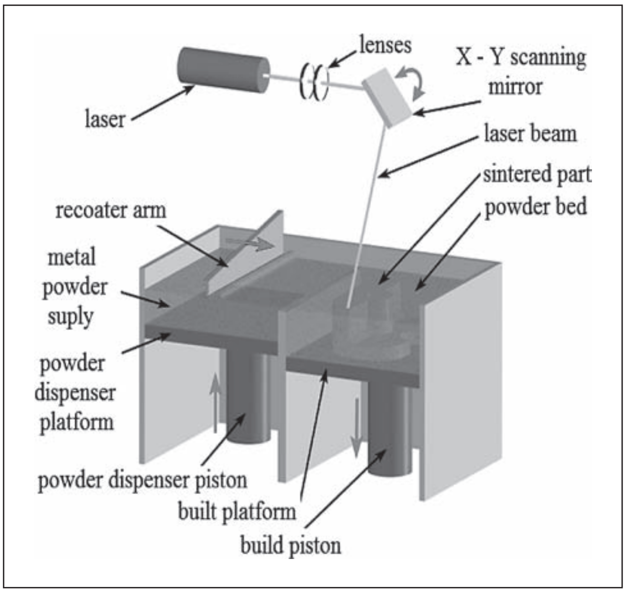


**Figure 1** Direct metal laser sintering principle

Parts build in EOS MaragingSteel MS1 have a chemical composition corresponding to US classification 18 % Ni Maraging 300, European 1,2709 and German X3NiCoMoTi 18-9-5. This kind of steel is characterized by having very good mechanical properties, and being easily heat treatable using a simple thermal age-hardening process to obtain excellent hardness and strength. [7] The chemical composition of the tested material is in Table 1.

Table 1 **Chemical composition of tested material / wt. %**

| Fe | Ni | Co | Mo | Ti |
|---|---|---|---|---|
| balance | 17-19 | 8,5-9,5 | 4,5-5,2 | 0,6-0,8 |
| Al | Cr, Cu | C | Mn, Si | P, S |
| 0,05-0,15 | each ≤ 0,5 | ≤ 0,03 | each ≤ 0,1 | each ≤ 0,01 |

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Two series of samples were manufactured by 3D printer. The first one (labelled VZ1) was manufactured only by using 3D printer with hardness 33 HRC but the second one (labelled VZ2) was post-hardened to 53 HRC by age-hardening at 490 °C for 6 hours.

Three planes (x - y, y - z, z - x) created by axes x, y, z were used for our examination.

Direction of layering of the sample and planes of measurements are displayed at the Figure 2. [8]

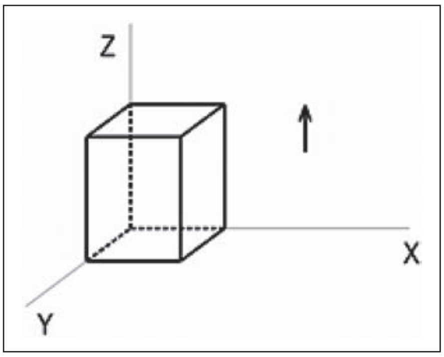



**Figure 2** Direction of layering of the sample and planes of measurements

Optical microscope was used for observation of microstructure and Hardness Tester CV-400DAT with different loads (1 000, 500, 300, 200, 100, 50, 25, 10 g) and duration of applied load 10 seconds provided by company CV Instruments was used for assessment of hardness. The sample used for observation of microstructure was grinded and polished with equipment provided by MTH Hrazdil, s.r.o. company and was etched by Nital. [9,10]

## RESULTS AND DISCUSSION

Hardness of assessed materials is showed at the Figures 3, 4. Figure 3 shows hardness by Vickers testing method. The highest value measured in the first series of samples without heat treatment was 361,5 HV1 and the highest value measured in the second series of samples treated by heat was 576,2 HV1 (1 000 g).

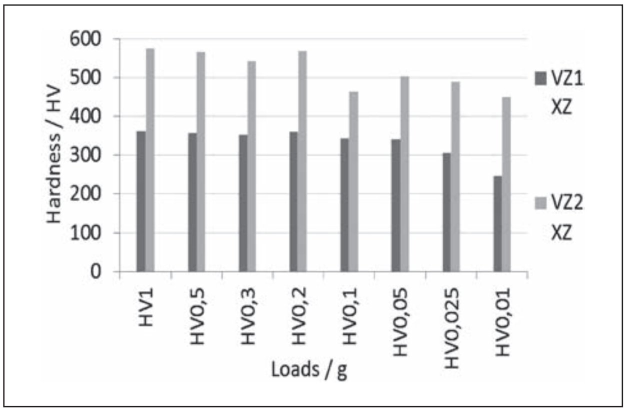



**Figure 3** Hardness of material assessed by Vickers Hardness Tester using different loads and measured in x - y plane

Values in both observed series of samples were lower with decreasing force. Values of hardness measured by Rockwell scale are displayed at the Figure 4.

In this case, values were similar to those measured by Vickers testing method. Specific values are showed in Table 2.

Figure 5, 6 shows values of microhardness measured in three planes by samples without heat treatment and with heat treatment. Their averaged values are given in Table 2. Again, lower values of hardness can be observed in samples produced without heat treatment.

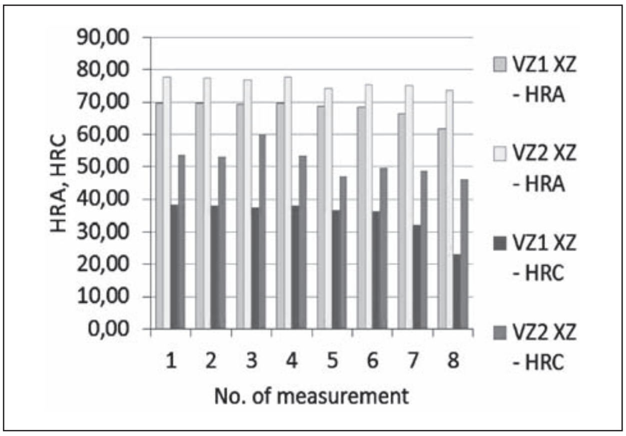



**Figure 4** Rockwell HRA, HRC testing method converted from Vickers testing method measured in x - y plane

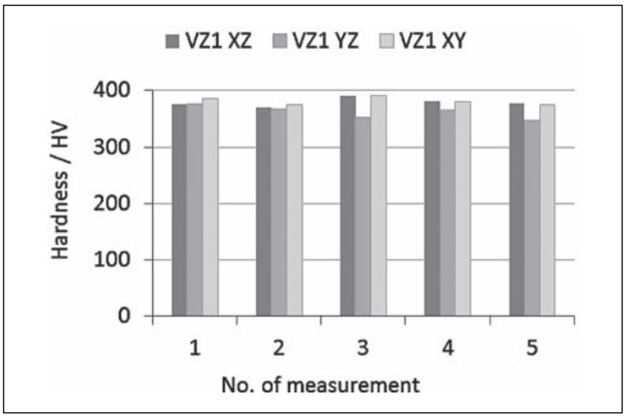



**Figure 5** Vickers testing of hardness in planes x - y, y - z, z - x / without heat treatment

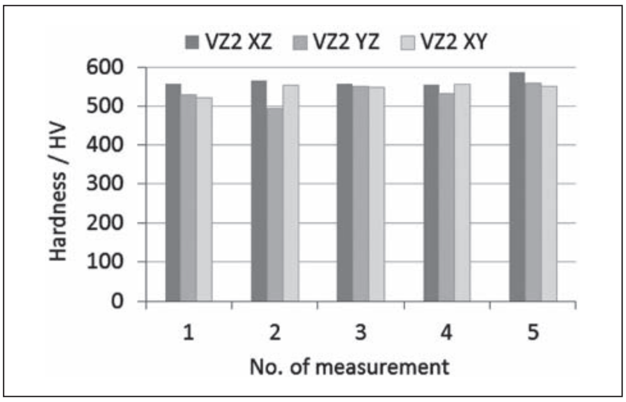
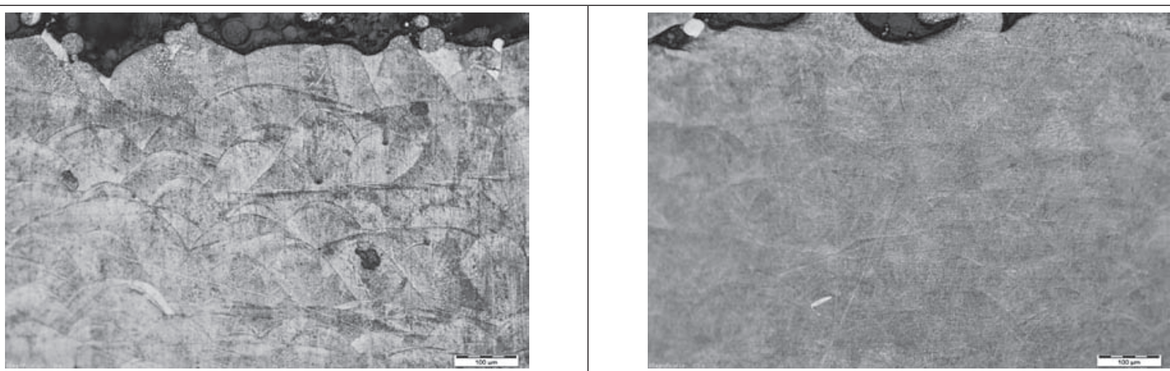



**Figure 6** Vickers testing of hardness in planes x - y, y - z, z - x / with heat treatment

The highest values were measured in planes x - z and x - y. The values measured in plane y - z were lower what is caused by layering of metal powder formed during sample production. Table 2 also shows percentage increase of the sample treated with heat. An increase in values of hardness by 46 % on average was achieved

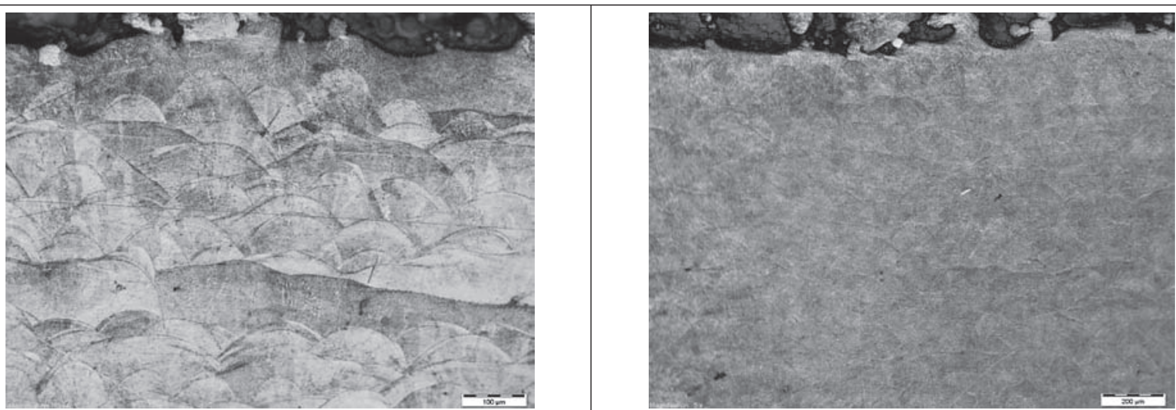
Table 2 **Values of hardness measured by using different loads**

| HV | HV1 | HV0,5 | HV0,3 | HV0,2 | HV0,1 | HV0,05 | HV0,025 | HV0,01 | ∑ |
|---|---|---|---|---|---|---|---|---|---|
| VZ1 | 361,5 | 357,6 | 352,9 | 358,2 | 342,6 | 340,0 | 305,7 | 244,9 | |
| VZ2 | 576,2 | 565,5 | 541,5 | 568,0 | 463,5 | 502,1 | 490,1 | 449,1 | |
| HRA | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | ∑ |
| VZ1 | 69,66 | 69,50 | 69,20 | 69,54 | 68,70 | 68,47 | 66,45 | 61,80 | 67,92 |
| VZ2 | 77,83 | 77,53 | 76,83 | 77,63 | 74,20 | 75,54 | 75,19 | 73,7 | 76,06 |
| HRC | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | ∑ |
| VZ1 | 38,40 | 38,00 | 37,50 | 38,1 | 36,50 | 36,12 | 32,13 | 23,17 | 34,99 |
| VZ2 | 53,83 | 53,22 | 59,89 | 53,39 | 47,00 | 49,56 | 48,81 | 46,00 | 51,46 |



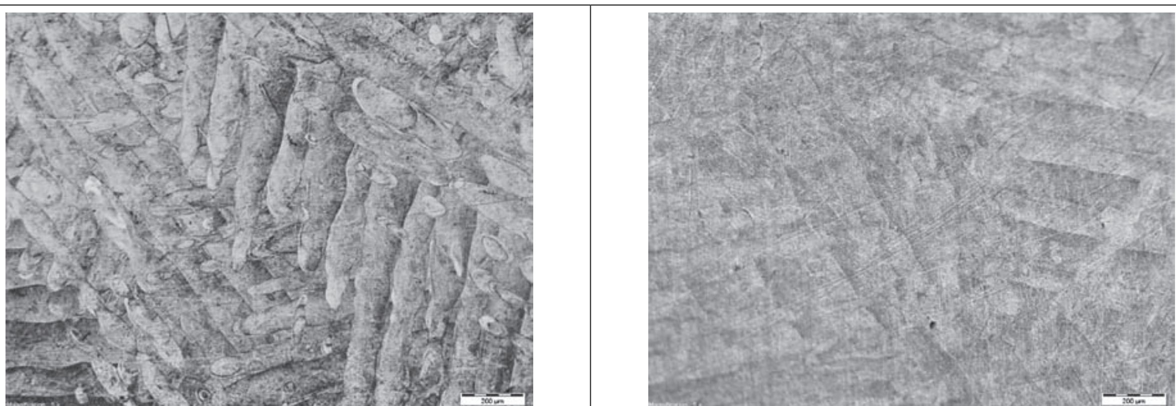
VZ1 Sample without heat treatment | VZ2 Sample with heat treatment

**Figure 7** Microstructures of the samples observed in plane x - z.



VZ1 Sample without heat treatment | VZ2 Sample with heat treatment

**Figure 8** Microstructures of the samples observed in plane y - z.



VZ1 Sample without heat treatment | VZ2 Sample with heat treatment

**Figure 9** Microstructures of the samples observed in plane x - y.

compared to the sample without heat treatment. Microstructures of both observed series of samples are showed at the Figures 7 - 9.

Figure 7 shows microstructure of the sample in plane x - z. Microstructural phases in plane y - z (Figure 8) were similar to those in plane x - z. The grains were placed to each other in a distance of 0,1 mm.

The samples without heat treatment VZ1 had different microstructural phases compared to the samples treated with heat VZ2.

The grains treated with heat were placed in acicular structure what is typical for materials with high hardness.

## CONCLUSION

Hardness of assessed materials was measured within the range 10 g to 1000 g. The value of hardness of the sample manufactured only by using 3D printer was 361,5 HV1 and of the sample treated with heat 576,2 HV1, i.e. the hardness of the sample treated with heat increased by 56 %.

The values measured by using Rockwell scale are as follows: the highest measured value of the sample without heat treating was 69,7 HRA (average value 67,92 HRA) and after treatment with heat 77,83 HRA (average value 76,06 HRA). The highest measured value of the sample without heat treating was 38,4 HRC (average value 34,99 HRC) and after treatment with heat 53,83 HRC (average value 51,46 HRC).

Measurement of hardness in three planes (x - y, y - z, z - x) proved that the highest values were measured in planes x - z and x - y. The values measured in plane y - z were lower what is caused by layering of metal powder formed during sample production.

Microstructure of assessed samples contained grains which were placed to each other in a distance of 0,1 mm.

The samples treated with heat contained grains forming acicular structure on the whole surface.

## Acknowledgement

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**Note**: The responsible for English language is Mgr. Lucia Gibľáková from Iluminata Linguistics, Lubica, Slovakia