INFLUENCE OF DEFORMATION ON THE HARDNESS DISTRIBUTION FOR CAR-BODIES MATERIALS

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Abstract

On the materials for car-bodies are posed quite tough requirements. As the most important of them there are tendencies to still lower car-body weight (to apply lightweight materials) as well as on the other hand also effort to improve its safety because of passengers. Quite a lot of material properties (e.g. Young´s modulus, yield strength, ultimate strength, ductility, etc.) enter into such effort. Last but not least there is also hardness that represents another very important material property. This paper deals with the measurement of hardness in dependence on deformation of tested materials. The major aim is from static tensile test to determine their deformation behavior (namely strain hardening exponent) and subsequently to measure surface hardness distribution as 3D color map surface. And finally to make conclusions from such results which arise from the experimental data especially in the area of non-uniform deformation (necking area).

Keywords: Car-body, hardness, deformation, 3D color map surface, necking

1. INTRODUCTION

Both hardness and formability represent a very important material property and that´s why this paper deals with the evaluation dependence of hardness on the given deformation. Moreover, there was also monitored hardness distribution on the sample surface via the 3D color map surfaces. In the experimental part were tested two materials with the different deformation behavior. First one was a deep-drawing material DC06 and the second one was stainless steel DIN 1.4301. Their basic mechanical properties are written in **Table 1** and engineering stress-strain curves are shown in **Figure 1 -** left. Already from this properties is evident their totally different deformation behavior [1, 2]. Especially strain hardening exponent *n* [1] differs a lot (*n* = 0.25 and 0.41, resp.) [3]. Such values were then used during measurement of hardness HV2 distribution which was carried out on the hardness tester Qness Q30A (see **Figure 1** - right) [4].

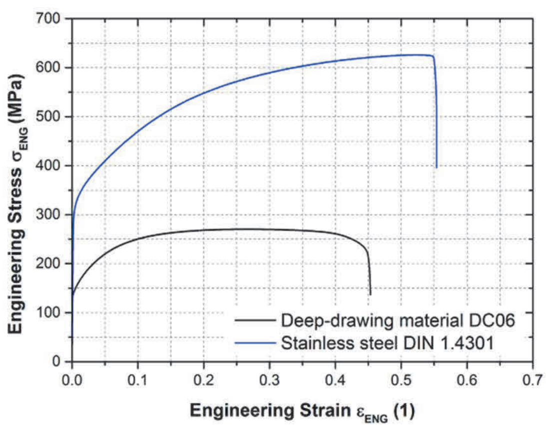

Figure 1 Engineering stress-strain curves for tested materials (left) and hardness tester Qness Q30A (right)

Table 1 Mechanical properties of deep-drawing steel DC06 and stainless steel DIN 1.4301

Material / Mechanical property	Yield strength $R_{p0.2}$ (MPa)	Ultimate strength R_m (MPa)	Uniform ductility A_g (%)	Total ductility A_{80mm} (%)
Deep-drawing steel DC06	143.2	271.4	25.76	45.87
Stainless steel DIN 1.4301	310.5	627.4	51.57	55.25

2. METHODOLOGICAL BASES AND EXPERIMENTAL PART

The first step of experimental part was hardness values determination in pre-defined (by X-Y coordinates) points on the specimen´s surface. **Figure 2** shows such results for DC06 as images taken from hardness tester in dependence on applied engineering strain with the following sequence: 0 % - 10 % - A_g (25 %) and A_{80mm} (45 %). In the left corner is display the relevant hardness HV2 value: 80.3 - 105 - 114 - 128 HV.

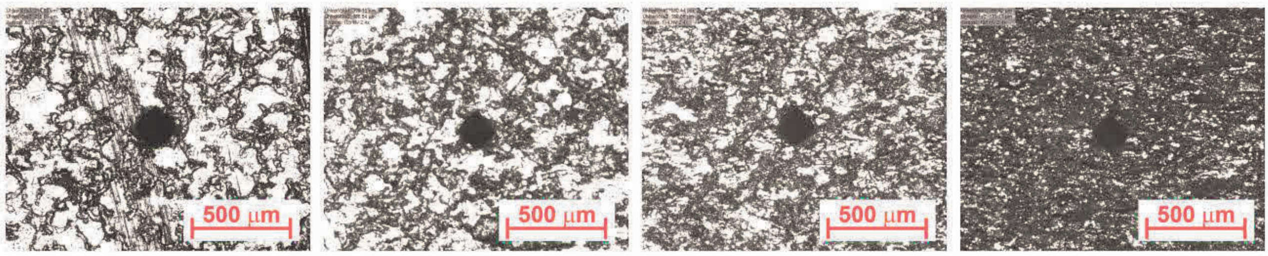

Figure 2 DC06 - hardness HV2 images in dependence on engineering strain: 0 % - 10 % - A_g - A_{80mm}

Figure 3 also shows hardness HV2 images, now for the 2nd tested material - stainless steel DIN 1.4301. Regarding the different deformation behavior of the material, also values of applied engineering strain differs. Namely 0 % - 25 % - A_g (51 %) and A_{80mm} (54 %) and hardness HV2 values: 180 - 300 - 347 - 382 HV.

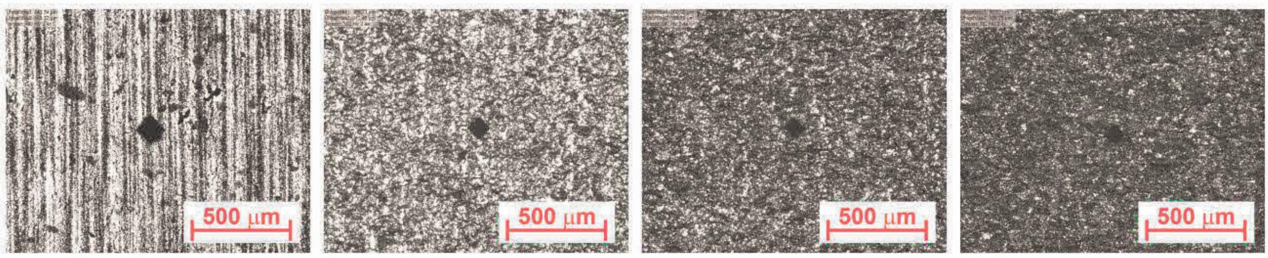

Figure 3 DIN 1.4301 - hardness HV2 images in dependence on engineering strain: 0 % - 25 % - A_g - A_{80mm}

Because the main aim of this paper was not only to measure hardness HV2 in dependence on applied strain but especially to characterize hardness distribution on the specimen´s surface, as a major graphical results there were used 3D color map surfaces. One of them is as an example shown in **Figure 4** (for stainless steel DIN 1.4301 and A_{80mm} as engineering strain). Black dots represent the own measured hardness HV2 values (3D scatter graph). Smaller black dots then display projections of these values on XY, YZ and ZY planes. For better clearness are in **Figure 4** (left) shown also drop lines along Z-axis. In **Figure 4** (right) is than shown the major 3D color map surface through measured dots and also as a flat one on the bottom of XY plane.

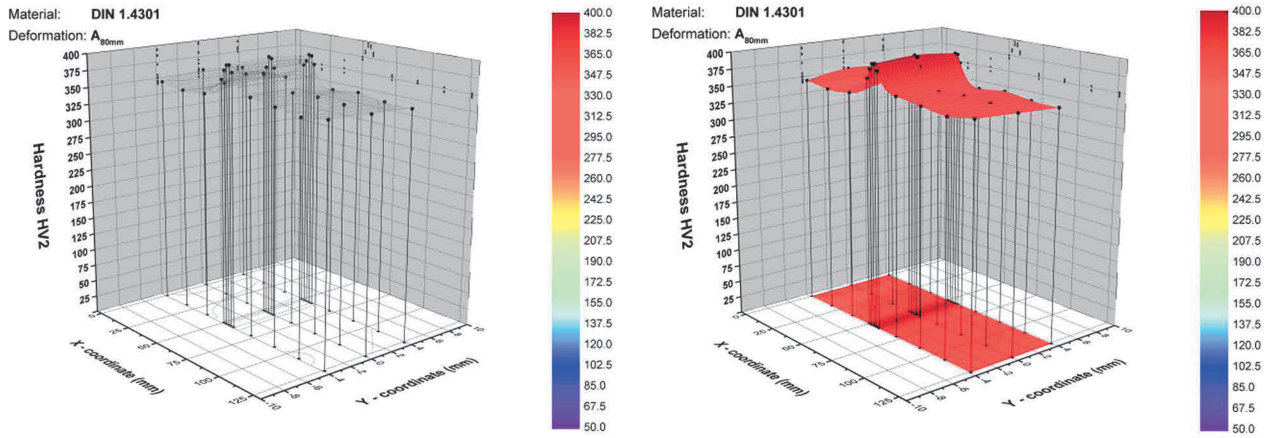

Figure 4 3D color map surface only as a mesh through measured points (left) and filled by color map (right)

2.1. Results for the deep-drawing material DC06 and the stainless steel DIN 1.4301

As it was described in the previous chapter, the 3D color map surface graphs were taken as the major graphical result. Such graphs for both materials are shown in the following figures. In the **Figure 5** are displayed 3D color map surfaces for DC06 and 1^{st} three applied engineering strains: 0 % - 10 % - A_g (resp.).

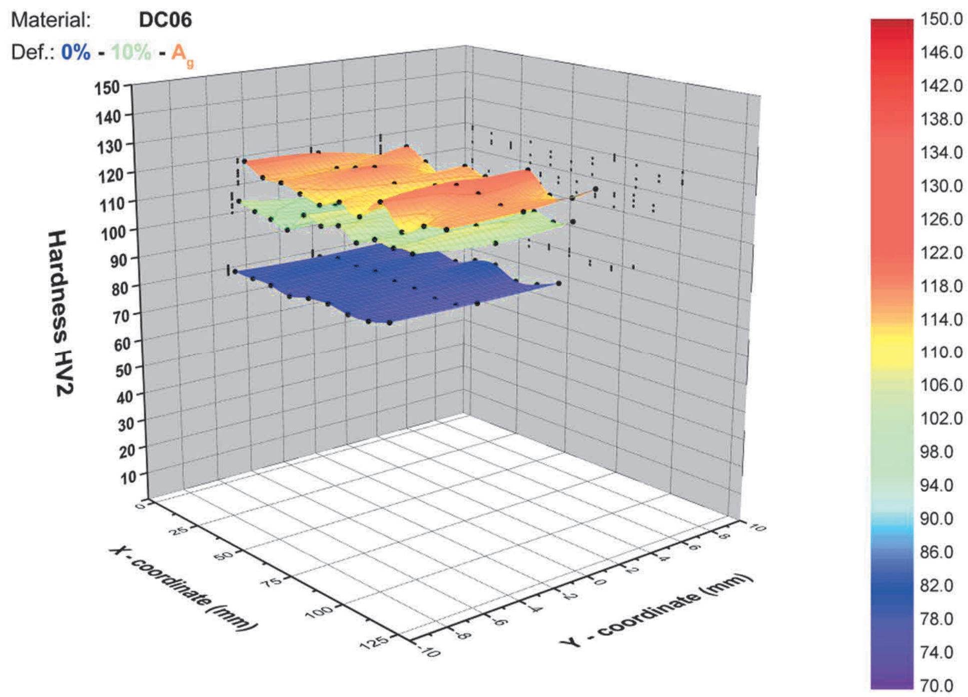

Figure 5 DC06 - 3D color maps surfaces for 1^{st} three applied engineering strains: 0 % - 10 % - A_g (25 %)

In the **Figure 6** are finally shown the hardness HV2 results for final ductility (A_{80mm}). It provides interesting information both about the hardness values and distribution of them - especially rapid increase in the necking area and almost the same results as A_g in the area without necking (homogenous deformation).

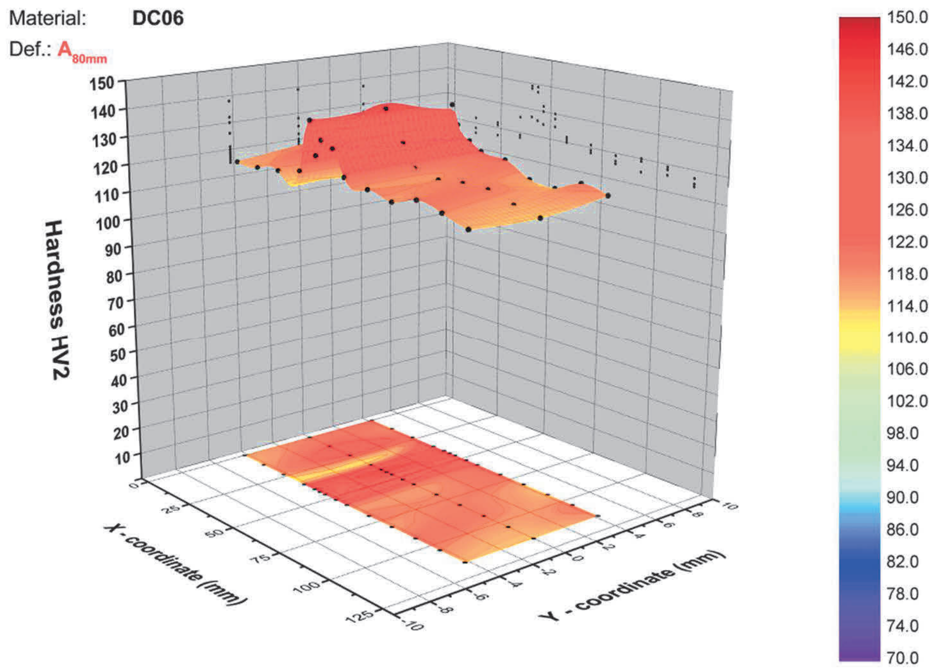

Figure 6 DC06 - 3D color map surface for the last applied engineering strain: A_{80mm} (45 %)

Because of quite high strain hardening exponent (n = 0.41) of stainless steel DIN 1.4301, there was a strong presumption about rapid increase of hardness HV2 magnitude up to the uniform ductility A_g. **Figure 7** illustrates such results and it´s evident that this increase is both high and homogenous in light of its surface distribution. Such homogenous distribution is good shown by projection of hardness values on YZ plane.

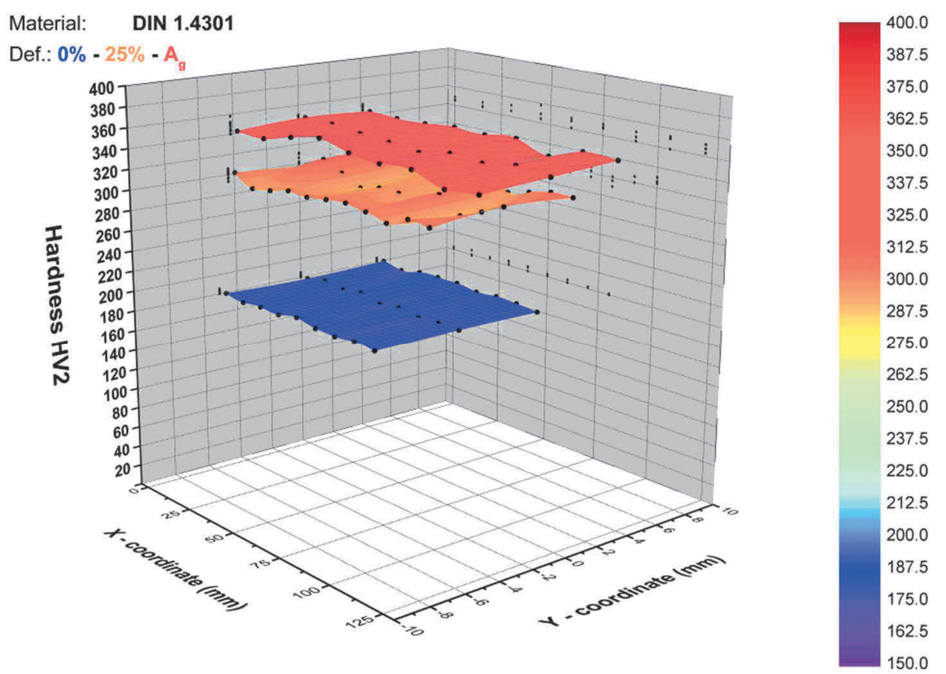

Figure 7 DIN 1.4301 - 3D color maps surfaces for 1st three applied engineering strains: 0% - 25% - A_g (51%)

Another typical deformation behavior of stainless steel DIN 1.4301 is fact that magnitudes of uniform A_g and total A_{80mm} ductility are quite similar. Final deformation (taken as difference between A_{80mm} and A_g occurred only in the necking area and from the results (see **Figure 8**) is clear that it increased approx. by 40 HV.

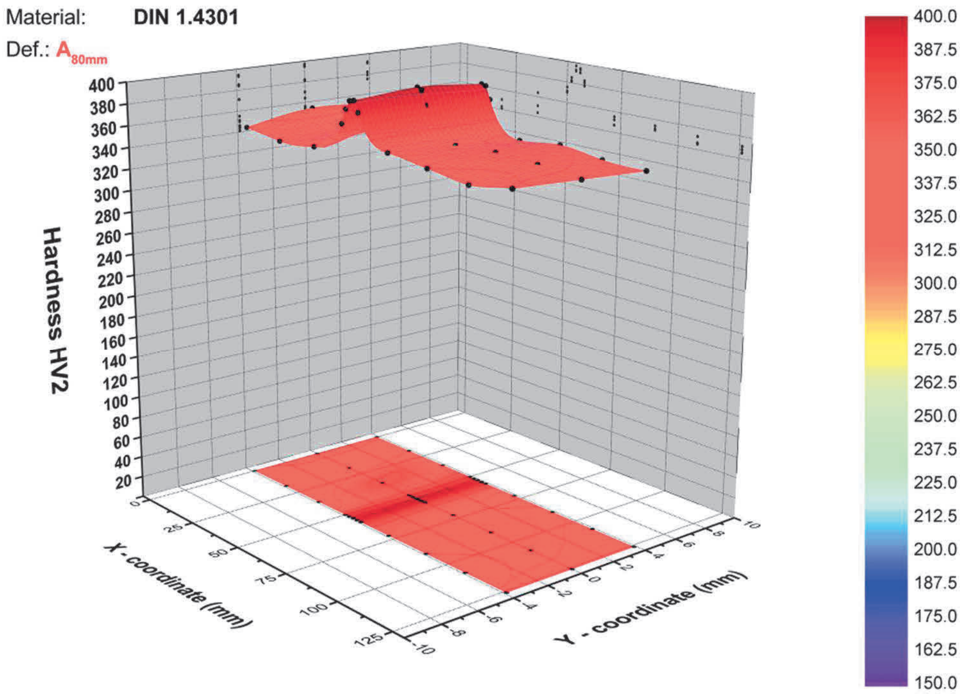

Figure 8 DIN 1.4301 - 3D color map surface for the last applied engineering strain: A_{80mm} (54 %)

In the **Table 2** are summarized results of hardness HV2 in dependence on the applied deformation of specimens in light of engineering strain ε_{ENG} (1). Major conclusion is clearly evident, the higher engineering strain, the higher hardness. Results of hardness for final applied strain (A_{80mm}) are divided into 3 major groups (total magnitude, necking area and without necking area) to highlight difference between necking and area without necking influence. Graphically are results (inc. detailing of A_{80mm}) shown in **Figures 9** and **10**.

Table 2 Results of hardness HV2 for both tested materials and all applied engineering strains

Deep-drawing steel DC06			Stainless steel DIN 1.4301		
Engineering strain ε_{ENG} (%)		**Hardness HV2**	**Engineering strain ε_{ENG} (%)**		**Hardness HV2**
0 %		**79.1 ± 1.2**	0 %		**181.9 ± 1.7**
10 %		**103.8 ± 2.2**	25 %		**300.3 ± 5.3**
A_g (25 %)		**115.1 ± 2.8**	A_g (51 %)		**347.3 ± 4.0**
A_{80mm} (4 5%)	**- total magnitude**	**122.3 ± 6.8**	**A_{80mm} (54 %)**	**- total magnitude**	**364.3 ± 18.8**
	- necking area	**131.3 ± 5.5**		**- necking area**	**384.7 ± 8.7**
	- without nec. area	**118.7 ± 2.6**		**- without nec. area**	**349.6 ± 5.2**

There is evident rapid increase of hardness in dependence on engineering strain. For DC06 is such increase given by 31 % - 46 % and 66 % (necking area) and for DIN1.4301 by 65 % - 91 % and 111 % (necking area).

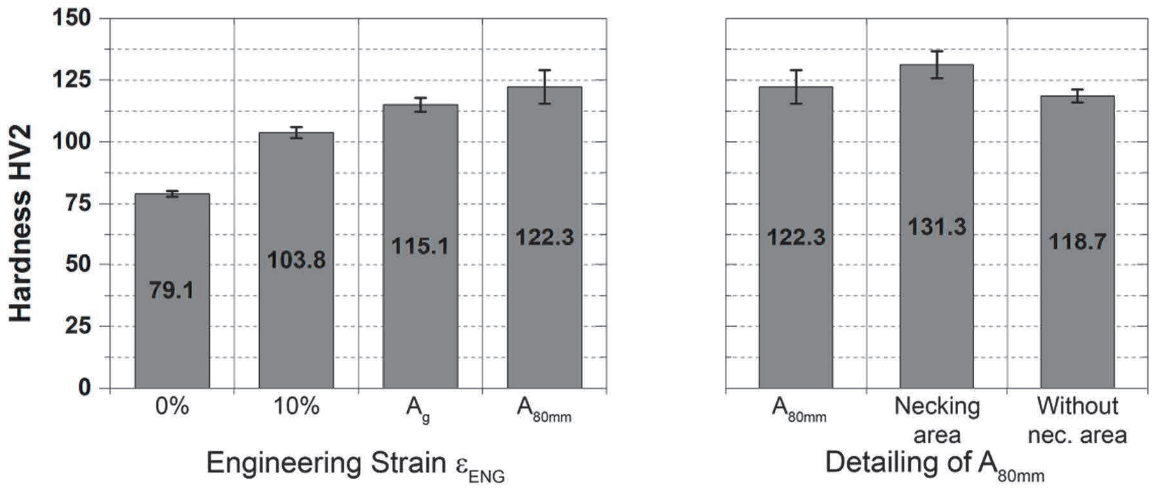

Figure 9 DC06 - hardness HV2 vs. engineering strain and its detailing for A_{80mm}

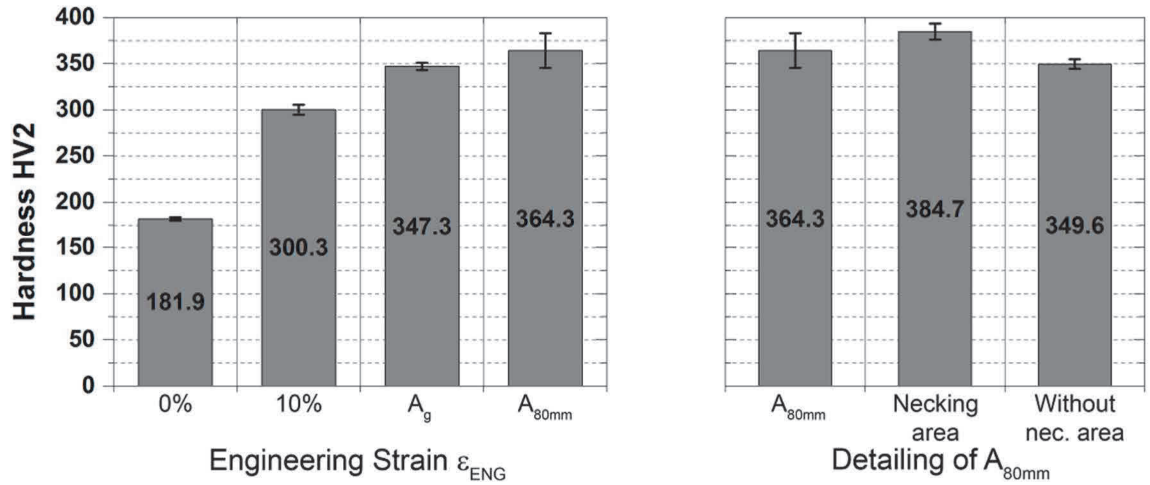

Figure 10 DIN 1.4301 - hardness HV2 vs. engineering strain and its detailing for A_{80mm}

3. CONCLUSION

The major aim of this paper was to determine influence of deformation on the final values of hardness for materials with the different deformation behavior. That´s why as tested materials were chosen deep-drawing material marked as DC06 and stainless steel (DIN 1.4301). Acc. to their engineering stress-strain curves, the following engineering strains were applied: 0 % - 10 % (25 %) - A_g and A_{80mm}. To obtain 3D color map surface, final hardness values were measured on the specimen´s surface (black dots in the 3D graphs). Due to utilization of these 3D graphs it was also possible (beside the common statistical evaluation by arithmetic mean and standard deviation) to clearly observe the own hardness HV2 distribution on the specimen´s surface - especially between A_g and A_{80mm} to monitor influence of the necking area (see **Figure 11**). The future research should concern about calibration strain-hardness curves for more materials.

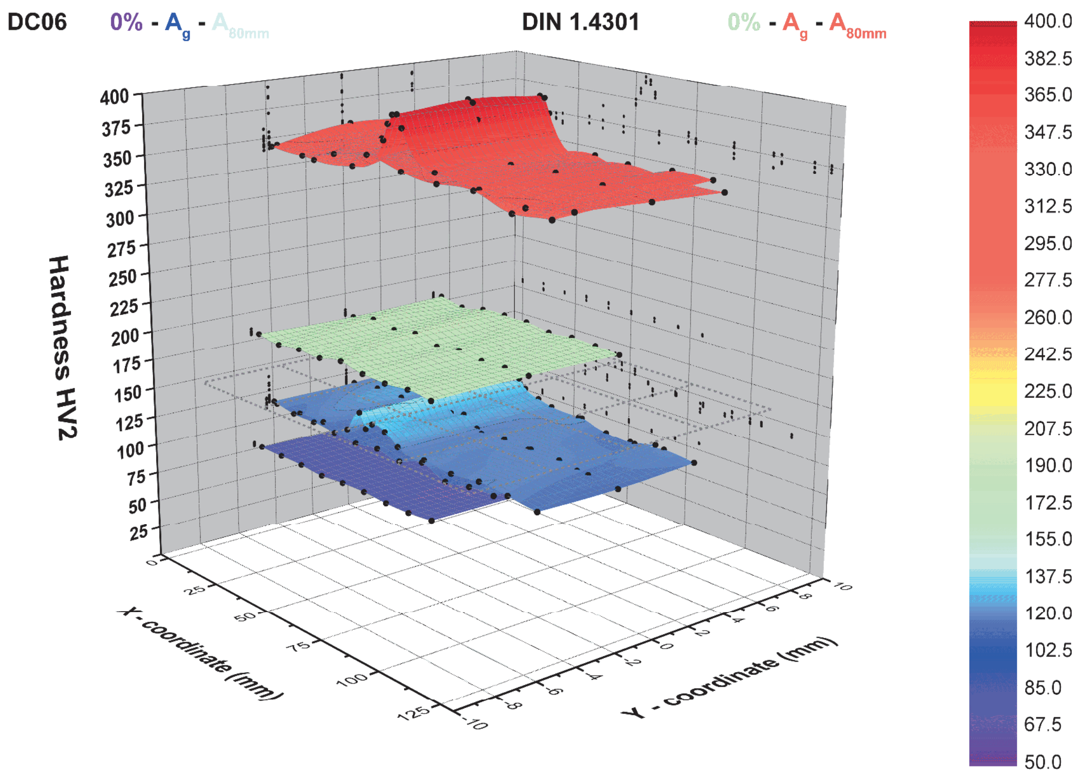

Figure 11 Final comparison of hardness distribution for both tested materials (separated by plain grey mesh)

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