EVALUATION OF THERMAL INFLUENCE IN THE MANUFACTURE OF SPUR GEAR WHEELS BY USING PLASMA

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The aim of this paper is to provide the readers with information related to the modern trend in manufacturing the spur gear wheels by using plasma. The gear-wheels, which are characterised than one of the elementary components of mechanism and machines parts, represent very important and in the several cases irreplaceable constructional element. In the recent years there isn´t expressive innovations of their type´s shape but in the present it starts beating up technology of production. It was on based upper of requirements on their precision and production voluminosity for shortening production time. It is reason why constructers and research personnel find of solution for reaching their scopes. At the present the Department of Design Technological Equipment, Faculty of Manufacturing Technologies TU in Košice, doing research in the dissertation thesis which is focused on face gearing production by plasma. This research is continued on work of Ing. Jozef Maščenik, PhD. [5] who dealt optimization of technology gearing production by progressive technologies. On based his result of tests it is demonstrated that for gearing production is the best applying of plasma. So on based presented reason paper deals deeper analysis of thermals influences in the gearing production using plasma.

🗝 Key words: gear-wheel, hardness, plasma, production, structure

1 The current state in technologi of production gearing-wheels

Current know methods of gear-wheels production represent width area for application different technologies but main dividing is on progressive technologies and traditional of gearing production. [4,10]

Progressive technologies of gear-wheels production are water jet cutting, laser cutting, spark-wire machining and plasma cutting. These technologies presents new trend of gear-wheel production. [3,5]

The traditional technology is machining for example milling, gilling and slotting of gear-wheels. To this group it classifies gear-wheels production by plastic deformation (it´s rotary shaping gearing-wheels), heat-forging and cold-forging of gear-wheels. Follow methods of gear-wheels production are: casting, gear-wheel production by powder metallurgy and plastic gear-wheel production. [3,6].

Gear-wheels with higher precision are finished by shaving which is used for untempered wheels; grinding than next operation of machining or heat-treatment; lapping for heat-treatment gear-wheels by cementation, nitriding and hardening. For hardening of gear-wheels are used: induction consistent hardening, induction single-shot hardening, fame hardening consistent and fame hardening single-shot by flame [7,10]

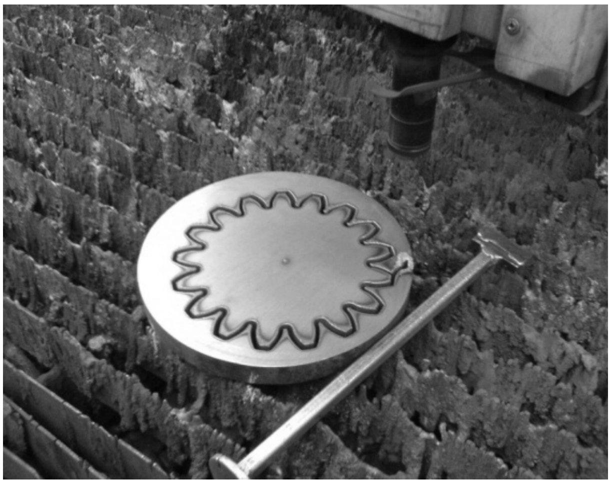

Fig. 1 Gear-wheel cutting by plasma Formica Nitra, For CUT 203 WDM
Obr. 1 Ozubené koleso delené plazmou typu Formica Nitra, For CUT 203 WDM

2 Face gearing production using plasma

The production of gear-wheels was realized at companies Weldex, s.r.o. and Tomark, s.r.o. in the Prešov. These companies have a long tradition and experiences in a field of plasma cutting. It was reason why research was realized in these companies. Cutting plan emanated from conception of gear-wheel, with module m=12 and teeth number z=17, which is produced in the ZŤS Sabinov. For cutting equipments was necessary to prepare cutting plan on based of drawing in the AutoCad. Experimental material addition from drawing of gear-wheel was 0,8 mm because of overall dimensions was modified with this dimension. This modified drawing not be able to use because equipment can´t process it. Because of drawing was transformed on cutting plan. With using of software "AsperWin-Basic" model of cutting plan was modified for plasma equipment Formica Nitra, For CUT 203 WDM.

There was modified dimension of gear-wheel about correction 2 mm. This width of cutting is gap which is created plasma cutting. In a case of Hypertherm HyDefinition HD 4070 couldn´t use late plan because equipment doesn´t support this plan. New plan was created in "WinPlasma CR Elektronic" with correction 2 m. This correction is depended on thickness of material which is 25 mm. Material was chosen steel 16MnCr5.

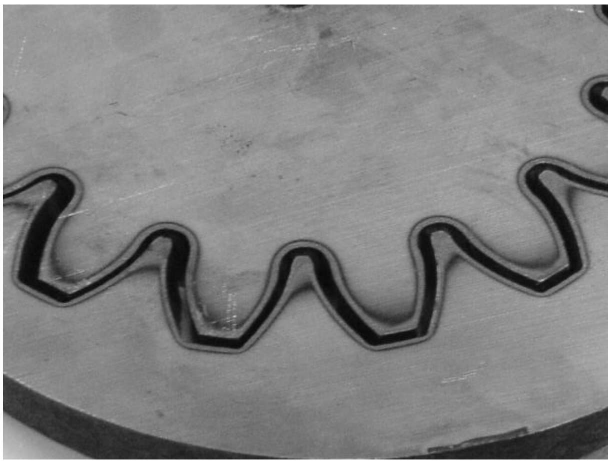

Fig. 2 Burnt of gear-wheel cutting by new generation plasma type Hypertherm HyDefinition HD4070
Obr. 2 Výpalok ozubeného kolesa deleného plazmou typu Hypertherm HyDefinition HD4070

First sample of gear-wheel was cut in the Weldex, s.r.o. There was used plasma Formica Nitra, For CUT 203 WDM and nozzle for burner CENTRICUT C55-033, Type 225A with diameter 2,1 mm. Diameter of nozzle was chosen on based dividing flow 180A, tension 165V and cutting gas O_2. Cutting speed was 820 mm.min^{-1} and time of cutting was 56 seconds. Gear-wheel burnt which was cut by plasma is on Fig.1

Second sample was cut in the Tomark, s.r.o. There was used new generation of plasma type HYPERTHERM HyDefinition HD4070. It was used nozzle with blue marking which is dimensioned for flow 200A. This property was convenient for cutting tension with value 180V. Gas for preignition of plasma beam and protecting gas was used N_2. Cutting gas was O_2. Cutting speed was 1060 mm.min^{-1} and cutting time was 45 s. On Fig. 2 is burnt of gear-wheel which was cut by new generation plasma type Hypertherm HyDefinition HD4070.

For research was used in a both cases new components: nozzle and electrode than defects on based erosion of these components were eliminated and cutting quality was better.

3 Metallographic Analysis of Gearing

In terms of metallographic tests, in the initial part of the research, we focused on metallographic testing by means of an optical microscope and performed a mechanical hardness test pursuant to Vickers (STN EN ISO 6507-1), which is also the subject-matter of the presented paper. A prerequisite for further research is also the performance of additional tests in the area of metallography, e.g. electron microscope testing, X-ray and electron difractography, etc.

3.1 Metallographic testing by means of an optical microscope

For a microscopic analysis, suitable samples in the form of microsections needed to be prepared. In general, preparation of microsections includes operations regarding the extraction of samples, sample preparation, sample grinding, polishing and a final development of the structure by means of short-term etching of the surface of the sample with a 2 per cent solution of nitanol, washing in a water stream and the subsequent treatment by means of ethyl alcohol while being intensively blow-dried until the surface is completely dry. Thereafter, the sample is ready to be used for observation under a microscope. [1,8]

In our case, this was no different. The only deviation was due to the fact that in the process of sample extraction, we needed to ensure that the extraction process of the material does not cause additional thermal transformations in the material itself. This would, in the end, cause the measurement results to be distorted. [2,9] In both cases, that is in the case of gearing produced by means of Formica Nitra, For CUT 203 type plasma and the new generation Hypertherm Hy Definition HD4070 type plasma, the cogs have been cut using a band saw designed to cut metal – ergonomic 275.230 DG with emulsion band cooling.

For research purposes in both cases, samples from the gearing have been taken from the cog head picture 3, cog side and cog base. The presented paper deals solely with the samples extracted from the cog head in case of the gearing produced by means of ordinary plasma (abbreviated OP), we chose to denominate Formica Nitra, For CUT 203 WDM type plasma, due to its common and popular use in production practice. The new generation Hypertherm Hy Definition HD4070 type plasma has been denominated exact plasma (abbreviated PP), due to its efficiency and cut width. The cog head samples for OP and PP have been extracted from at the pitch circle of the gearing, that is, at a distance of half of the pitch circle from the center of the cog wheel (d/2=102 mm). This approach has been selected owing to the fact that the gearing includes the already mentioned additional material.

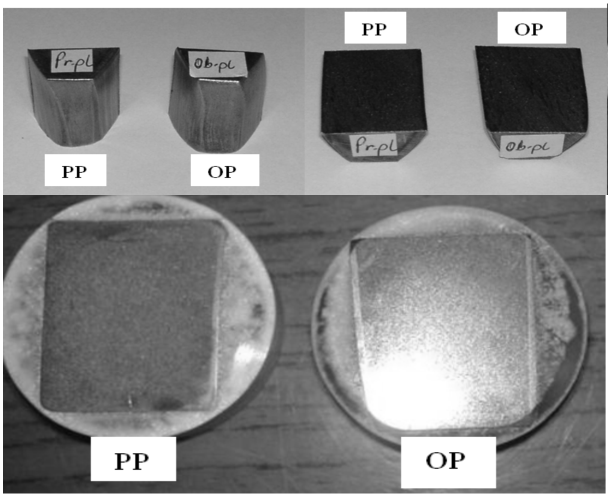

Fig. 3 Cog Sample Form with PP and OP, extracted from cog faces before being coated with dentactyle; below dentacryle coated cog samples
Obr. 3 Tvar vzoriek ozubenia PP a OP, ktoré boli odobraté z hláv zubov pred ich zaliatím do dentakrylu a dole zaliate vzorky ozubenia do dentakrylu

This material is 0,8 mm in width around the whole circumference of the gearing as well as a correction of 2 mm. The correction has been chosen due to the technology of the plasma and the cutting edge width, which, in the end, enlarges the width of the gearing by this additional dimension. Should wee seek the diameter of the pitch circle from the cog head surface, this would lead to a greater error, caused by the unevenness of the surface, resulting from the plasma shear. In this manner, we have avoided the mentioned situation and created a surface fit for observation, representing the surface of the actual gearing at the pitch circle. The resulting surface for observation has been significantly larger than what is the standard for use as microsections, where the standard size is 10 x 10 x 10 mm. In the present case, we needed to acquire such a large surface to be able to research it in a reasonable amount of detail and establish what processes take place in the various parts of the gearing due to the heat of the plasma.

For reasons of better handling, the samples have been coated in dentacryle and left to harden. Afterwards, they have been ground using a circular piece of sanding paper. The sanding paper grit size has been changed as follows: 80, 120, 240, 400, 800, 1200. The grinding procedure has been performed using a laboratory grinding machine type Metasinex in such a manner that when changing sanding paper grit for a finer size, the sample was washed in water and turned by 90 degrees before additional grinding was performed. When the required surface has been achieved, it has been checked under an EPITYP 2 microscope by CARL ZEISS (DDR) and polishing was performed. The polishing procedure was performed using a Struers laboPol – 5 device with an automatic sample preparation adapter. Blue polishing paste MetaDi 1 µm by BUEHLER was used. After checking the sample using the EPITYP 2 microscope, the etching of the samples was initiated. The samples designated for etching were required to have a nice reflexive surface without scratches. The structure to be observed has been developed using short-term etching of the sample surface with a 2 per cent solution of nitanol MilFe ($5cm^3$ HNO_3, $100cm^3$ Ethanol 96% C_2H_2OH). The etching time for the various samples was rather short – the sample was emerged into the solution and immediately afterwards washed under water. The samples have been subsequently washed in pure ethyl alcohol and intensely dried by means of a hot air blower until the surface was completely dry. Now, the samples were ready for observation under the microscope. The initial observations of the structure of both samples of the gearing of the OP and PP have been performed using a Micro-Vickes hardness tester, Mode: 400DAT (2008).

This device has been fitted with a digital camera by means of a special lens adapter to be able to document the appearance of the observed structure of the cog surface. The research showed that the basic material of the gearing is a ferritic perlitic steel. Judging the steel structure, it was not possible to exactly determine the carbon content but from the material sheet of the steel we know it is a cementing Mn-Cr steel with a maximum carbon content of 0,14 to 0,19 per cent. More details will be revealed in a more detailed analysis using the electron microscope, which will be performed in terms of further research. The exact chemical make-up of the steel may be also arrived at using an X-ray quantometer at the ARL (Applied research Laboratories) or using a Scanning microscope. The Micro Scanning method does not allow us to establish the precise carbon content, just the content of some other elements, like: Fe, Al, Si, Cr, Mn.

Figure 4 represents the overall structure of cog head sample material cut by means of OP from the edges of the sample towards the center, using a 50 x zoom. As can be seen in the picture, in the upper left part at the cog front, the material structure was transformationd due to heat of the plasma. This transformation is initially larger with a size of about 500 µm in depth of the material from the edge of the cog surface and is gradually decreasing in size to 200 µm downwards, where the plasma burner jet cuts through the material. This strip is the most intensive and represents a direct contact of the material and the jet of the plasma burner upon cutting. The change in the thickness of the heat tempering in this area may be explained by the fact that when cutting, the plasma jet is hotter on the upper side of the material and it affects the material for a longer time and with higher intensity, until the product is completely severed.

Overall, this area absorbs more secondary heat from the jet, which causes the observed transformations in the material, dependant on the duration of exposure After this layer, another follows - the so-called inter-layer. It is a layer in between the basis material and the first, most affected layer by the heat. Determining its dimensions is rather difficult as when observed, this layer does not exhibit a similar transition as the previous one – it does not proceed from a wider to a more narrow surface but from a more narrow to a wider surface. The reason for this is that in the lower part of the sample, this surface reaches into the area where, theoretically, based on the transformations observed on the from side, an area of stronger heat-induced transformation should be visible but it is not. This is caused by the uneven heating up of the material during plasma cutting whereby the area most affected by the heat is the incision point. It is on approximately that we may say that at he top area of the gearing, the affected surface is 400 μm thick and later extending to a thickness of 700 μm. Mode details may be provided by a hardness test of the material in these areas, which should prove the findings from the uncovered material structure. The last layer is the already-mentioned basis material – the material not significantly affected or not affected at all by the heat. This material should have (and has) a structure identical with the structure of the uncut material.

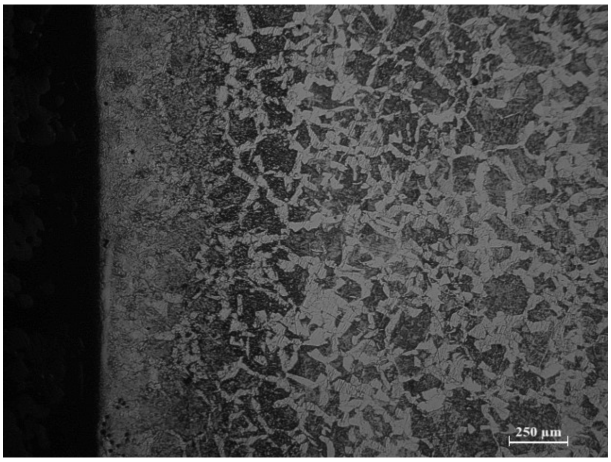

Fig. 4 Cog head structure with OP, 50 x zoom
Obr. 4 Štruktúra hlavy zuba OP, zväčšenie 50 x

It was rather interesting to observe the cog head sample structure cut by PP. This sample also exhibited transformations in the material but not in the extent as it was with the previous sample (Fig. 5). When observing the sample, we may state that only two layers were created. The first layer is, just like in the previous case, the layer with the most significant heat transformation. The scale of the transformation in the upper left part of the sample is about 300 μm and it is gradually decreasing to about 200 μm. This means that the time of exposure to the heat has been significantly shorter and the cutting speed faster, which is an undeniable fact.

The PP guarantees a cutting angle of 3 degrees, which is in general more suitable for cutting material with higher precision and with a higher quality of the cut. By means of a more detailed observation of both samples, we have established that in both cases, in the first area, a more intensive transformation in the material takes place, which provides conditions for the creation of bainitic or martensitic or a mixed bainitic and martensitic steel structure at the same time. Mode information may be provided by further microscopic analysis by means of an electron microscope, where an extremely large magnification up to 1000x is possible.

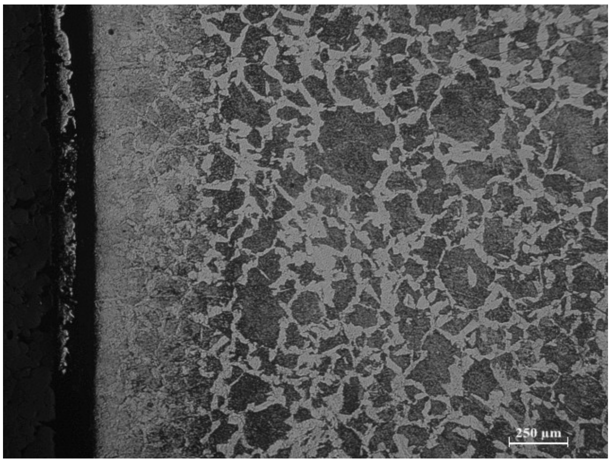

Fig. 5 Cog head structure with PP, 50 x zoom
Obr. 5 Štruktúra hlavy zuba PP, zväčšenie 50 x

3.2 Gearing hardness measurement

The material hardness has been tested by means of Vickers testing using a Micro-Vickers hardness tester, Model: 400DAT (2008). The advantage of this test is that the results are theoretically not dependant on the force of the stressing body. The exactness of the test depends mostly on the exactness of the device, on the surface structure and homogenity of the tested material.

The measurement took place on both samples of the cog wheels cut using OP and PP using a stressing force of 1,961 N for 10 seconds. The individual incisions were at a distance of 10 μm and each sample has been measured 25 times. The measurement has been initiated at a distance of 12,5 mm, that means in the center of the sample from the left edge, as shown in Fig. 4-5. The overall gearing thickness was 25mm. Only one side of the cog surface has been tested for hardness – the left one – and in the future, the same measurement will be performed on the right side to be able to judge whether there is some form of transformation present which would be symmetrical.

Mode data on the measurements may be found in tables Tab. 1 and Tab. 2. Based on the measurements, we may conclude that there is a correlation between the changing hardness and the changing structure of the material.

Distance l[mm]	0,05	0.015	0,025	0,035	0,045	0,055	0,065	0,075	0,085	0,095	0,105	0,115	0,125
Hardness [HV0,2]	554,9	465,9	419	575,9	288,1	213,8	419	347	275,9	228,9	199	197,2	207,1
Measurement No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Distance l[mm]	0,135	0,145	0,155	0,165	0,175	0,185	0,195	0,205	0,215	0,225	0,235	0,245	
Hardness [HV0,2]	169,6	170,6	192,6	209	174	176,4	205,3	200,2	166,2	173,8	204,1	200,2	
Measurement No.	14	15	16	17	18	19	20	21	22	23	24	25	

Tab. 1 Measured Cog Hardness Values for OP
Tab. 1 Namerané hodnoty tvrdosti zuba OP

Another finding is that the chosen material must be prepared with an emphasis on higher quality to be able to exactly determine further, more precise measurements and observations of the samples in terms of metallography.

Distance l[mm]	0,06	0.016	0,026	0,036	0,046	0,056	0,066	0,076	0,086	0,096	0,106	0,116	0,126
Hardness [HV0,2]	413.4	398.6	343,6	286,1	382,8	339	370,7	226,8	233,6	234,7	216,9	233,6	235
Measurement No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Distance l[mm]	0,136	0,146	0,156	0,166	0,176	0,186	0,196	0,206	0,216	0,226	0,236	0,246	
Hardness [HV0,2]	191,5	180,1	184,1	188,3	184,7	210,8	202,9	198,2	197,7	194,9	187,7	204,1	
Measurement No.	14	15	16	17	18	19	20	21	22	23	24	25	

Tab. 2 Measured Cog Hardness Values for PP
Tab. 2 Namerané hodnoty tvrdosti zuba PP

4 Conclusion

Modern production technology of frontal cog wheels using plasma cutting, an overall shortening of the production times and increase in production output may be achieved. To be able to arrive that this result, we need to understand the thermal transformations take place in the material when using plasma cutting. The established facts will help us understand the processes in the material dependant on the type of plasma used, which will help to determine the specific type of plasma to use not just in production of cog wheels but also in other areas.

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Vyhodnocovanie termického vplyvu pri výrobe čelných ozubených kolies plazmou

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Cieľom príspevku je poskytnúť čitateľom informácie zahrňujúce poznatky v oblasti výroby čelných ozubených kolies plazmou. Problematike sa zaoberáme v rámci riešenia dizertačnej práce autora príspevku. V úvode článku opisujeme súčasné stavy výroby ozubenia, ako aj možné spôsoby ich dokončovania. Ďalej sa podrobne venujeme opisu výroby čelných ozubených kolies plazmou. Na výrobu ozubenia u čelných ozubených kolies sme použili plazmu dvojakého typu a to plazmu typu Formica Nitra, For CUT 203 WDM a plazmu novej generácie Hypertherm HyDefinition HD 4070. Obe plazmy sú pri delení charakterizované svojimi špecifikáciami a tak sme ich vo výskume, pre lepšiu orientáciu pomenovali skratkami. Plazmu typu Formica Nitra - skratkou OP a plazmu novej generácie Hypertherm - skratkou PP. Tieto skratky používame aj pri rozlišovaní vzoriek delených práve týmto druhom plazmy. Na Obr. 1 je znázornené ozubené koleso delené OP, a na Obr. 2 koleso delené plazmou PP. Obe tieto kolesá vychádzajú z jednotnej koncepcie ozubeného kolesa s modulom m=12 a počtom zubov z=17, vyrábaného v praxi trieskovým obrábaním firmou ZŤS Sabinov. Na týchto ozubených kolies je volený experimentálny prídavok materiálu 0,8 mm z dôvodu uvažovanej tepelne ovplyvnenej oblasti, ktorá je nežiadúca a je potrebne ju odstrániť pre ďalšie technologické operácie obrábania a dokončenia ozubeného kolesa na požadovaný rozmer. Súčasne je na ozubení volená tiež deliaca medzera v podobe korekcia 2 mm pre technológiu delenia plazmou, čo predstavuje materiál, ktorý sa vplyvom tepla plazmy vyparí. Voľbu korekcie sme určili v programe „AsperWin-Basic“ pre OP a v programe „WinPlasma CR Elektronic“ pre PP pri zostavovaní plánov delenia ozubených kolies, na základe druhu a hrúbky deleného materiálu. Materiál ozubenia je cementačná oceľ 16MnCr5 a hrúbka ozubenia 25 mm. V rámci metalografických skúšok, sme sa zamerali v prvopočiatku výskumu hlavne na metalografickú skúšku optickým mikroskopom, a mechanickú skúšku tvrdosti materiálu podľa Vickersa (STN EN ISO 6507-1), čo je náplňou príspevku. Na Obr.3 je znázornený tvar vzoriek ozubenia PP a OP, ktoré boli odobraté z hláv zubov pred ich zaliatím do dentakrylu a dole, tiež na tomto obrázku sú už znázornené zaliate vzorky ozubenia. V tejto časti príspevku sa tiež podrobnejšie venujeme príprave samotných vzoriek, ako aj spôsobu ich odberu. Práve dôslednosti prípravy vzoriek je potrebné venovať veľkú pozornosť a precíznosť, lebo od nej záleží aj celkovo správne vyhodnotenie štruktúry, a relevantnosť nameraných výsledkov. Na obrázku Obr.4 a Obr. 5 je znázornená celková štruktúra vzoriek hláv zubov od okraja vzorky smerom do stredu materiálu, podľa použitého druhu plazmy, pri zväčšení 50 x. Tieto štruktúry majú premenlivý charakter v závislosti od tepelného ovplyvnenia plazmy. Sú členená na jednotlivé oblasti. U OP prvú oblasť tvorí najviac teplom ovplyvnená zóna, potom nasleduje užšia vrstva v podobe medzivrstvy a nakoniec vrstva základného materiálu. V porovnaní s PP tu dochádza ku intenzívnejšiemu tepelnému vplyvu o čom svedčí aj šírka jednotlivých pozorovaných oblastí. Pohľadom na vzorku PP by sme mohli tvrdiť, že tu vznikli len dve vrstvy. Prvou je, tak ako v predchádzajúcom prípade vrstva s najväčším tepelným ovplyvnením materiálu a potom je prechod na druhú, ktorú tvorí základný materiál, cez veľmi ťažko identifikovateľnými hranicami medzivrstvy. Podrobnejším skúmaním oboch vzoriek sme došli k názoru, že v prvej oblasti a to u oboch vzoriek dochádza ku intenzívnejšiemu pretvoreniu materiálu a je tu predpoklad vzniku bájnitickej, poprípade martenzitickej, alebo zmiešanej, aj bájnitickej aj martenzitickej štruktúry súčasne. Viac nám napovie ďalšia analýza v rámci mikroskopie, pomocou elektrónového mikroskopu. V tabuľkách Tab.1 a Tab.2. sú údaje o nameraných hodnotách tvrdosti ozubenia pre vzorku hlavy zuba OP a PP. Meranie sa uskutočnilo pri zaťažujúcej sile 1,961N, dobe pôsobenia záťaže 10s. Vzdialenosť od jednotlivých vpichov bola 10 µm a počet meraní pre každú vzorku 25 krát. Meranie bolo zahájene v strede vzorky OP a PP vo vzdialenosti 12,5 mm, teda presnejšie v strede vzorky od ľavého okraja, pri pohľade tak, ako pozeráme na obrázok Obr. 4-5. Z nameraných hodnôt môžeme konštatovať, že existuje tu závislosť meniacej sa tvrdosti spolu s meniacou sa štruktúrou v materiály. Ďalším zistením je aj fakt, že volený experimentálny prídavok materiálu je potrebné upraviť na vyššiu hodnotu, ktorú presne potvrdí ďalšie podrobnejšie meranie a pozorovanie vzoriek v rámci metalografie. Novodobou technológiou výroby čelných ozubených kolies plazmou, by bolo možné docieliť skrátenie celkových výrobných časov a zvýšenie objemnosti výroby. Na to, aby sme to docielili potrebujeme poznať ku akým termickým zmenám dochádza v materiály, pôsobením tepla plazmy. Zistené zmeny nám pomôžu pochopiť prebiehajúce procesy v materiály aj v závislosti od použitia typu plazmy, čo celkovo napomôže predurčiť použitie plazmy aj v iných oblasti.

ZPĚT