ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering

Tome XII [2014] – Fascicule 1 [February]
ISSN: 1584–2665 [print]; ISSN: 1584–2673 [online]
a free–access multidisciplinary publication
of the Faculty of Engineering Hunedoara

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MANUFACTURABILITY AND SURFACE QUALITY OF STAMPING PUNCH SHAPED SURFACE

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Abstract: The paper describes stamping punch production from the view manufacturability and quality of stamping punch active surfaces. The tin car–body stamping punch has been chosen as a subject of experimental work. The experimental stamping punch has been made out of Pertinax and production stamping punch has been made out of tool steel X210Cr12. Milling strategies has been proposed and verified using CAM software SolidCAM considering the maximum Scallop Height. The roughness parameters Ra and Rz measured on selected areas of stamping punch shaped surface were compared to Scallop Height. Manufactured areas on shaped surface were optically evaluated as well. The application of proposed procedure is shown as an example of manufacturability for experimental and production stamping punch designed for complex parts production.
Keywords: milling strategies, stamping punch, roughness, scallop height

1. INTRODUCTION

Components with shaped surfaces are made by various technological processes, whereby their form is frequently obtained in the direct contact with a production device – a die, a casting form, a form for die–casting of plastic materials or a compression molding device. The industry, from the aviation production to the domestic appliance production, in a large extend uses the compression molding technology for a production of required parts. The shape–complicated surfaces are often on such component parts from which complex shapes of forming devices are derived. By reason of high costs for forming devices, the design of a suitable technological process is the key factor.

In the production of devices, giving their shape to manufactured components, it is frequently necessary to put contradictory requirements into accordance e.g. the production time minimizing in achieving of the required accuracy of parameters and a surface quality. In such cases, the implied technology of a device production represents the significant role. If a forming device was manufactured by machining and cutting technologies, it would be necessary to also deal with appropriate strategies. In CAM system, the notion strategy of machining presents pre–defined tracks of a device, optimized for machining of various shape surfaces to make a product in the most effective way.

Nowadays, a wide scale of CAM systems is available, supporting a design of a component part production by machining. Those systems contain also simulation devices for a verification of the production proposed process, what helps a technologist to eliminate inaccuracies and deficiencies in advance of a production. The typical work progressiveness in CAM system for a project of production technological design of a component by machining process consists of the following activities: the emplacement of a component model in a working area, the zero point setting, the semi–product selection, the rougher strategy selection, the pre–completing and completing strategies selection, the assignment of devices and cutting conditions, the machining simulation and the NC code generation. The decisive role in shape components production is the selection of machining suitable strategies for manufacturing of individual surfaces and choosing of suitable flow for individual works [1].

The aim of the described activities was to manufacture a towing tool of a testing and subsequently also production towline device for pressing of a model automobile bodyshell, which was created within the framework of a project *SteelPARK – Creative factory*. The project is focused on the popularization of science and technology, mainly among young people [2]. The testing towing tool was used for a verification of suggested production process, the production of testing models series and to particularize suggested parameters of towing. The experience obtained from the production of the testing device was used for manufacturing of the production tool. The measurements of the surface roughness at various areas of a shape surface and the documented surface topography were subsequently done on the both towlines.

2. LITERARY PREVIEW

In manufacturing of surface areas by machining on milling machines the copy cutter is used in a finishing process in most of the cases. That cutting device removes an addition material along created traces and leaves surplus material in the form of combs (undulations) between adjacent tracks of the device. Because the height of a comb defines a surface roughness and affects also a dimensional accuracy, therefore it is required for it to obtain the lowest values as possible. The comb height is possible to decrease by a higher density of the device tracks and by using a device with a bigger diameter. The selection of a device diameter is the most frequently affected by parameters of manufactured surfaces and a space around them. Regarding those facts, in the NC program creation process a device with the biggest diameter is selected, so generally it is not possible to decrease the cope height by another increase of a device diameter. Denser traces of the device lead to the increase of manufacturing periods of time and therefore also to the increase of manufacturing costs. Usually cutter shape areas are consequently modified by hand for the purpose of tracks removing after a milling operation and for an acquirement of a smoothed surface. The task is to define such a density of a milling machine which will set manufacturing periods of time and costs of both the operations (the milling operation and the hand–operated finishing process) at the lowest level as possible. One of the solutions is a creation of such traces of devices which will ensure the constant height of undulations, so called iso–cusped tool paths, by which the hand–operated finishing process will be more effective. The description of various process is stated e.g. in [3]. In that source a possible process to obtain such traces is also stated whereby the height of undulations is presented from values of given surfaces tolerations.

The current selection methods of suitable strategies still require responsible decisions of a technologist – an NC programmer, e.g. in the before mentioned selection of a device parameter or the setting of distances between adjacent traces of a device. Excessively big diameter of a milling machine does not allow an access to some areas for a work–piece, a small diameter of a device invokes the necessity to increase the number of junctions on a machined surface. If spacing between the traces is too big, the result is an increased roughness of a surface, on the contrary by the decreasing of the spacing the time for machining is increased. For the solution of that problem e.g. the authors [4] suggested the analytical method for CNC machining of shape surfaces, based on the five steps: the detection of a surface equation, the curving analysis, the selection of tools, the calculation of deviations between a required and obtained surface and the calculation itself of the distance between adjacent traces of the device.

The example of the standard cutter strategies evaluation is stated e.g. in [5]. Three various finishing strategies in machining of a shape surface are compared under the same conditions. A surface texture, roughness and parameter accuracy were evaluated. The time of machining, the real one and from the simulation, was also compared. The work session [6] deals with a design, evaluation and optimalization of strategies. The author describes and evaluates particularly the strategies for the roughing and finishing processes. For roughing process he puts the emphasis on the biggest stock removal and the decrease of machining time, however at the same time the requirement is to create a consistent surface for the following finishing operations. In the strategy selection for the finishing operations, it is necessary to take into account on the one hand the shape, size and local curving of work–piece surfaces and on the other hand the shape and geometry of the device.

Despite complicated shapes of dies for their production, 3–axis milling operation is sufficient. It is caused by the way those devices are used during which a pressed material or a forged piece is needed to be removable from a device cavity without any problems. The direction of the pressed material removal is parallel with a cutter device axis, manufacturing a surface of a dies. Shearing strains on side wall of devices help to the removal of products.

The surface disparities, created after a technological operation, form the surface structure and therefore affect the surface utility in the future. The surface structure is divided into units according to the distance of relevant surface disparities. The unit with the smallest distance creating the surface roughness, the unit called the surface undulation and the unit with the biggest distance set by the basic profile belongs there.

The surface roughness represents the disparities height of a real surface in regard to the perfect and ideal smooth–faced surface created by the complex of the surface disparities, with relatively small distances which are created as an inescapable result of a production technology or other effects. The surface faults (accidental irregular disparities occurring occasionally) and also various material faults, damages and others are not counted for this case.

Nowadays, the quantities, standardized in STN EN ISO 4287, are used for the evaluation of surfaces roughness. The calculation system, for the evaluation of parameters of a surface profile in terms of the stated norm, is based on the system of the middle line of the roughness profile, the undulation and the middle line of the primary profile. The evaluation of a surface roughness is implemented by the parameters of a roughness profile marked as R. The roughness profile is derived from the basic profile by the compression of elements with a long wave longitude with the profile filter λc and it creates the base for the evaluation of the roughness profile parameters.

The evaluation of the surface roughness is possible with the profile method using juncture profilomets. The method enables to detect the number values of standardized and non–standardized characteristics of the surface micro–geometry. The method implementation is ensured by juncture (point) devices – profilomers. The sharp point of a profilomer scanner transfers a decomposition of disparities on a surface to a mechanical move which is subsequently transferred, by the scanner, to an electric signal and further elaborated and interpreted as the number value of the surface structure parameter which was selected, or eventually as a graphic record of the surface disparities profile.

3. EXPERIMENTAL WORK

The Figure 1 shows the car body of car model that has been taken as a complex shaped surface representative. Considering the stamping punch has a shape of car body, the selected surfaces to measure and compare roughness are labeled as roof, front window, front and rear hood. The shape of stamping punch was derived from virtual CAD model of car body.

Figure 1. Car body model

In the frame of experiments the stamping punch has been NC machined from two materials: the composite Pertinax and tool steel X210Cr12 (EN ISO 9676). The punch made out of composite was chosen to verify the proposed stamping process in experimental stamping die and to define desired blank shape for car body deep drawing in order to shorten production time of punch.

Pertinax, also known as a Karlit is composite material reinforced by cellulose paper joined by phenol–formaldehyde resin. Some material parameters of Pertinax are presented in Table 1 [7].

Table 1. Material parameters of composite Pertinax

Characteristics	Value
Bending strength vertically to layers [MPa]	150
Impact strength [KJm^2]	20
Compression strength [MPa]	120
Splitting resistance [N]	1700
Heat conductivity [$W.m^{-1}.K^{-1}$]	0.2
Coefficient of thermal linear dilatability [$1.K^{-1}.10^{-6}$]	20 ÷ 40
Temperature resistance (temperature index) [TI]	140

At planning of stamping punch production five alternatives of different strategy has been proposed. The roughing operation was considered the same for all proposed strategies and *contour* strategy had been used. The strategy, tool and cutting conditions in roughing were chosen in order to maximization of material removal and cutting time shortening. The *contour* strategy was chosen the best one from available ones in software SolidCAM 2009. The finishing allowance 0.4 mm was left after roughing operation. Proposed alternatives differ by sequence of operations while the best one was chosen by virtual surface analysis and computed total production time.

The sequence of four operations has been used in the chosen alternative. After the roughing the second operation means finishing upper surfaces of stamping punch using *parallel lining* strategy. The Scallop Height of 0.005 mm was set up for this strategy. The third one operation is finishing of stamping punch side walls using strategy of *constant Z*. The same value of Scallop Height 0.005 mm was used for this strategy, but for step down the range of 0.01 to 0.2 mm was set. The final operation finishes the stamping punch body. In this operation any pre–finishing operations has been used. Considering the properties of composite Pertinax any relevant influence to final surface quality of stamping punch body has been assumed.

The end mill with diameter Ø 10 mm has been used for roughing and the ball end mill with diameter Ø 4 mm was used for finishing of upper surfaces and side walls. Because of specific material has been machined, cutting conditions were derived from recommended ones for materials of group N. The cutting conditions were verified during workpiece preparation and adjusted to following ones:

– roughing: – cutting speed v_c = 106 $m.min^{-1}$, feed per tooth f_z = 0.06 mm,
– finishing: – cutting speed v_c = 62 $m.min^{-1}$, feed per tooth f_z = 0.02 mm.

The production stamping punch has been made out after verifying of proposed stamping process in experimental stamping die and defining desired blank shape for car body deep drawing. The tool steel of X210Cr12 has been used as a material of punch and knowledge gained during production of experimental punch from Pertinax were adopted. The production process and used strategies has been approved and adopted with any changes. Considering machined material, pre–finishing operation of upper surfaces was included in production process. Its purpose was to uniform allowance before finishing to 0.02 mm value. The parameters of finishing operation were optimized as well. When finishing the upper surfaces using *parallel lining* strategy the scallop height of 0.005 mm and maximum side step of 0.15 mm were chosen. Finishing of side walls of stamping punch by *constant Z* strategy was done using the same value of scallop height 0.005 mm, but step down was changed to the range from 0.01 to 0.15 mm. Tools were used the same as for production of experimental stamping punch made out of Pertinax. The cutting conditions were chosen by recommends of tool's producer for machined material as follows:

– roughing: – cutting speed v_c = 80 $m.min^{-1}$, feed per tooth f_z = 0.09 mm,
– finishing: – cutting speed v_c = 40 $m.min^{-1}$, feed per tooth f_z = 0.02 mm.

Machining of experimental and production stamping punches was performed on 3–axis CNC machine Emco Mill 155. Production times were the same as calculated ones by numerical simulations in CAM software. Comparison of experimental and production stamping punches is shown in Figure 2. The roughness of final surfaces in selected areas of stamping punch was done using profilometer Surftest SJ–301 by Mitutoyo. The equipment works on principle of surface scanning by diamond–point sensing head with radius 5 μm placed on sprung arm.

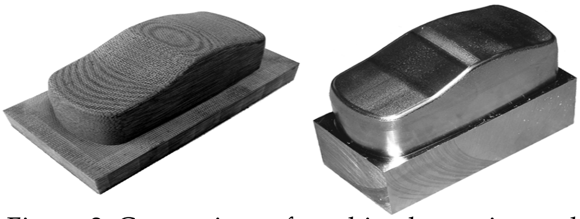


Figure 2. Comparison of machined experimental and production stamping punches

The parameters for surface roughness measurement were chosen based on the standard STN EN ISO 4287 as follows:

– λc profile filter – 0.8 mm,
– number of basic lengths N = 5,
– measured profile: R (median line system),
– filter: Gauss,
– evaluated length ln = 4 mm,

As measured parameters in terms of the standard STN EN ISO 4287 were chosen:

– Ra – arithmetical mean deviation of the assessed profile,
– Rz – maximum height of profile.

Measured areas of machined surfaces were also documented by microscope with sensing camera and 30–times magnification. Microscope Mitutoyo was installed on positioning unit of Surftest profilometer.

4. REACHED RESULTS AND EVALUATION

Roughness parameter Ra (arithmetical mean deviation of the assessed profile) is the basic and the most common evaluated parameter to describe surface microgeometry. But, when two surfaces are evaluated by Ra parameter, the same value of Ra might point to different surface morphology. Therefore, it necessary to use the other one roughness characteristic to differ evaluated surfaces more accurately. So, the Rz (maximum height of profile) has been chosen that is considered as comparable one to Scallop Height (SH) needed to set up in CAD systems [8].

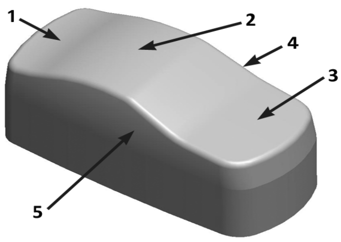


Figure 3. The stamping punch model with areas of surface roughness Ra and Rz measurement

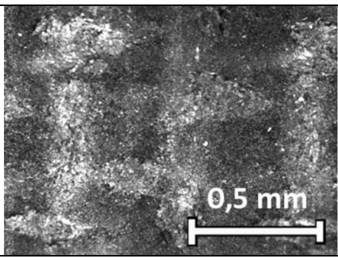
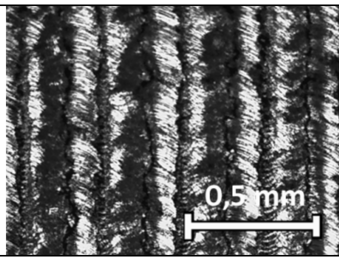
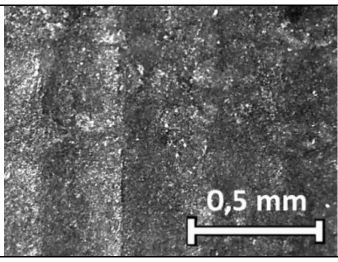
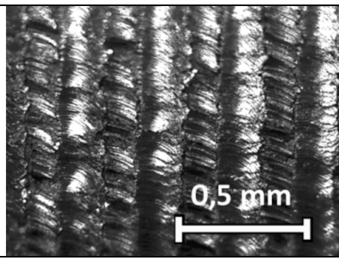
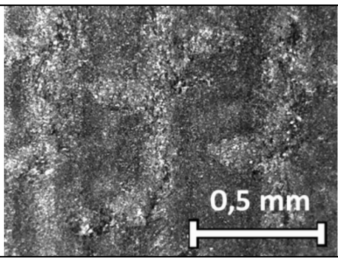
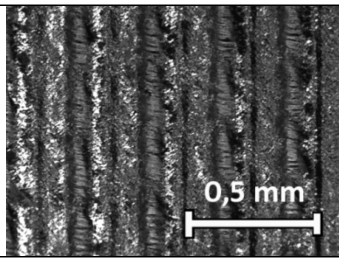
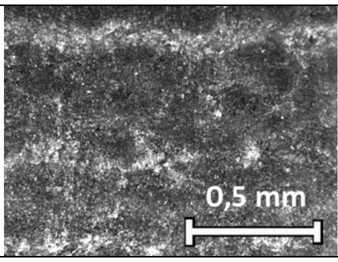
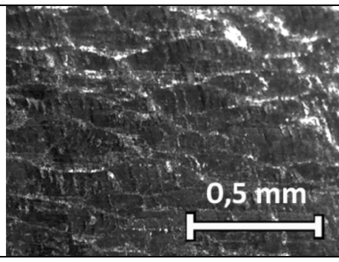
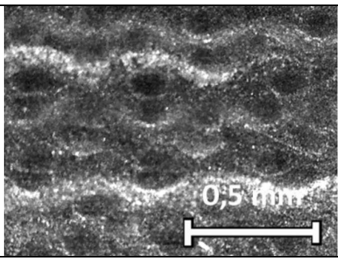
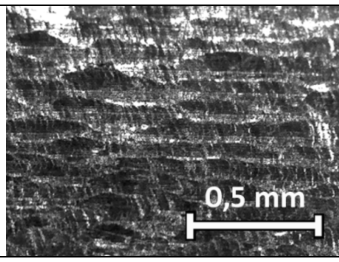
Figure 3 shows areas where roughness has been measured. Detail macroscopic views of top and side wall surfaces of experimental stamping punch made out of Pertinax are shown in Tab. 2 on the left. Upper surface of stamping punch (front hood, roof and rear hood) has been machined using *parallel lining* strategy that generates tool path in parallel 2D plains oriented vertical. Tool tracks are periodic and oriented parallel. The Rz surface roughness measured in these areas was from 10.75 μm to 14.45 μm. The side wall surfaces (fenders, doors) of stamping punch were machined using *constant Z* strategy. The principle of strategy is dividing the allowance to horizontal layers and material is removed in every layer by 2D cutting path. Side walls surface roughness Rz differ in 18 % while measured on the right and on the left. Layered cellulose paper coming out to surface is shown on detailed view in lighter areas.

The right side of Table 2 presents macroscopic views of top and side wall surfaces of production stamping punch made out of tool steel X210Cr12. Tool tracks on top surfaces are periodic and oriented parallel as well. The Rz roughness was measured in the range of 18.68 μm to 24.64 μm. Side walls surface roughness Rz differ in 32 % while measured on the right and on the left. Tool tracks are discontinuous and oriented horizontal.

The graph shown in Figure 4 compares measured values of arithmetical mean value Ra and maximum height of profile Rz to scallop height SH for surface of experimental stamping punch made out of composite Pertinax. The SH value has been set in CAM system the same for all finishing strategies. Measured values of Rz are in the range of 7.91 μm to 14.45 μm and they are 1.58 to 2.89 times higher than defined scallop height. Rz value is closest to SH value on the right side wall, the maximum difference is on the roof.

ISSN: 1584-2665 [print]; ISSN: 1584-2673 [online]

Table 2. Comparison of surface textures and roughness values for experimental materials

area	Pertinax	Ra [μm] Rz [μm]	Tool steel X210Cr12	Ra [μm] Rz [μm]
1		1.60 10.75		5.10 24.26
2		3.29 14.45		5.46 23.85
3		2.06 12.72		3.89 18.68
4		1.93 9.69		1.55 8.11
5		1.36 7.91		2.39 11.86

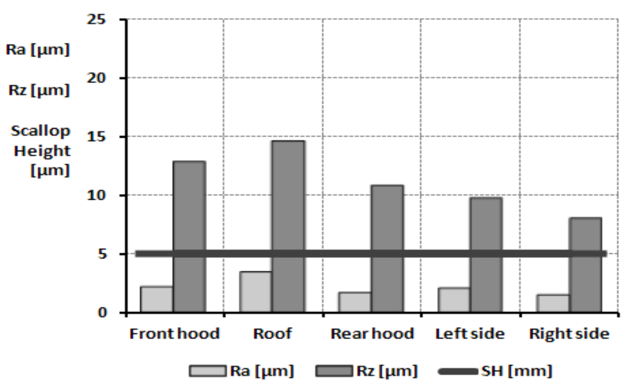


Figure 4. Comparison Ra and Rz roughness to scallop height SH for experimental stamping punch made out of composite Pertinax

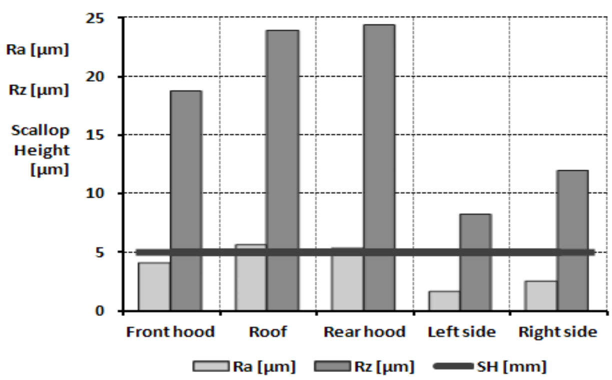


Figure 5. Comparison Ra and Rz roughness to scallop height SH for production stamping punch made out of steel X210Cr12

The graph shown in Figure 5 compares measured values of arithmetical mean value Ra and maximum height of profile Rz to scallop height SH for surface of production stamping punch made out of tool steel X210Cr12. The SH value set in CAM system was the same for all finishing strategies too. Measured values of Rz are in the range of 8.11 μm to 24.26 μm and they are 1.62 to 4.85 times higher than defined scallop height. Rz value is closest to SH value on the left side wall, the maximum difference is on the rear hood.

5. CONCLUSION

The aim of the experiments was to verify production of complex shape surface, such as the stamping punch of experimental and production stamping dies, made out of two materials: composite Pertinax and steel X210Cr12. Based on realized experiments and measured values of final surface roughness following outputs were observed:

- Knowledge gained during production of experimental punch from Pertinax allowed optimizing strategy and final surface quality to desired values in short production time and low production costs. The experimental stamping punch was used to verify deep drawing of car body in experimental drawing die and to define desired blank shape.
- The material Pertinax shown good machineability and it would be used for rapid production of experimental stamping punches and dies and deep drawing process optimization.
- Used strategy has substantial effect to machining as well as economic aspects of production. By choosing the proper strategy the production times might be decreased, the dimensional accuracy of part enhanced, surface quality improved as well as tool lifetime increased. Optimal tool path generation is key attribute of systems for NC codes programming.
- Comparing measured values of roughness in defined areas of stamping punch the higher values of Ra and Rz were measured when punch was produced from tool steel X210Cr12. For both materials the Rz values is higher than scallop height SH.

ACKNOWLEDGEMENT

Authors express their thanks for projects VEGA 1/0500/12 "Quality improvement when milling form surfaces by advanced milling tools" and VEGA 1/0396/11 "Research and optimization of methods for evaluation strength and plastic parameters of very thin tin steel sheets" supported by Scientific Grant Agency of the Ministry of Education, Science and Research of Slovakia.

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