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SELECTED ISSUES REGARDING AI-ASSISTED DESIGN OF SUPERHARD GRINDING PINS AND GRINDING WHEELS CAD MODELS

The article presents the use of the generative artificial intelligence (AI) in the process of a grinding pin and a grinding wheel CAD design. It presents the basics of the CAD design methodology and its verification in the CAD environment. Author applied ChatGPT™ developed by OpenAI company and the FreeCAD software along with Visual Studio Code™ software enabling for a Python code run in order to verify usability of large language model (LLM) of the generative artificial intelligence for the design process regarding CAD models of grinding pins and grinding wheels. The performed study revealed that artificial intelligence can effectively support the design process regarding grinding tools in selected design areas. It presented how the general geometry design can be supported by the AI. Moreover, it demonstrated an active layer design including modelling of textures and diamond grains. The approaches presented in the paper can be utilized in modelling of grinding processes and further AI-based developments of grinding pins and grinding wheels.

1. INTRODUCTION

Grinding process has been commonly used in industrial practice and it has been researched worldwide taking into account various process characteristics. Grinding wheels and pins play the crucial role in terms of process realisation, performance, utilization for various process variants [1, 2]. Grinding wheels and pins are known as tools which are used in finishing stages of technological process, and they are also applied in roughing operations, for instance in deep grinding of ductile materials [3] or in grinding of many types of hard and brittle materials such as ceramics, glass, carbides [4].

Grinding pins and wheels are characterized by various standard and special shapes and used materials. The most popular general division is based on the material type used. In this context, conventional (i.e. alumina or silicon carbide-based) and superhard grinding tools (i.e. diamond and cubic boron nitride (cBN)) are usually indicated by manufacturing sector [2]. Moreover, as it is demonstrated by the industrial practice (please refer to exemplary source [5]), the tools are characterized by various geometries and several important factors shall be

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taken into consideration during the design process and their adaptation to existing geometrical requirements linked to the grinding machine tools. For instance, a shape of a wheel and an abrasive layer geometry shape, width or depth are crucial in the case of specific features of machined parts, capabilities of machine tool kinematics, process technological parameters requirements, etc. In addition, grain parameters such as grain size or grain concentration along with the type of bonding material are key factors in terms of machined material type, machining type (e.g. roughing, finishing), machining results requirements (e.g. surface roughness) [5].

Continuously gained knowledge and the supply of innovations in the area of grinding have helped to create a lot of variants of the grinding tools. The developments have been extending available solutions of the tool design, process setups, machines, etc. Scientific and industrial literature analysis indicates that developments in the area of grinding tools play an important role both for scientists and industrial companies. Nowadays cleaner [6] and digitalization-based production of these tools and expected machining process efficiency (improved tool life, surface quality, part accuracy) linked to their usage is one of the key research aims. In this context, Wegener et al. [7] presented grinding wheels conditioning and monitoring principles and indicated several important research areas (e.g. promising structuring technologies). Ye et al. [8] investigated the efficiency-related issues regarding special grinding wheels (in fact grinding pins) having special lattice structure. Uhlmann et al. in their study [9] optimized grinding wheel design for flute grinding processes. Plichta et al. [10] developed special tools for internal cylindrical grinding by using scamper method of creative innovation design. Moreover, Barmouz et al. [11] investigated resin bond grinding wheels manufactured by using DLP (digital light processing) technique. Muthulingam and Uhlman in their work [12] researched different abrasive coating structures in double face grinding. The work developed by Jamshidi et al. [13] proposes wear model in grinding by using single-layer electroplated cBN tools. They inter alia presented several possibilities of grains modelling by using simple primitives. Wdowik R. at al. [14] verified various measuring techniques useful in the digitalization of grinding pins. These techniques have a potential to be used in measurements of tool wear or for process planning and modelling. Wdowik R. in the work [15] focused on research regarding surface texture parameters in the ultrasonic assisted grinding. Surface quality after grinding was also analysed in the paper of Żółkoś M. and co-authors [16].

Recent advances in the artificial intelligence (AI) accelerated research activities that are focused on various applications of the AI tools. Popular chats of various companies and research centers are simple and cost-effective tools enabling to generate code by using different programming languages. In this context, for the aims of CAD (computer-aided design) modelling, the FreeCAD software [17] is an open access CAD software tool enabling application of Python code for creation of various CAD models and other projects. However, these CAD models may also be created by using dedicated libraries of Python programming language [18] and the code can be run using dedicated console (e.g. Visual Studio Code™ [19]) and saved on the PC (personal computer) drive or in the cloud drive without specific CAD software assistance. It shall be also underlined that the research activities regarding the usage of the artificial intelligence for the aims of production and manufacturing engineering are accelerating in the scientific community due to AI fast developments. For instance, in the work [20] authors analysed the machine layout planning approaches, and the same team focused on AI-supported assembly design in the work [21]. These studies presented several pros and positive results but also limitations resulting from the "understanding of human instructions" by the LLM (large language model). Moreover, Deng et al. [22] utilized OpenSCAD software for gears modelling. Another team of Badagabettu and co-authors in the work [23] generated CAD models by using prompts and developed methodology.

The current study is directly focused on the verification of the AI-supported design of grinding tools (grinding pins and wheels) in terms of their selected characteristics such as their general geometry, textures and abrasive grain modelling. Possible beneficial applications and limitations resulting from AI-assisted design of grinding wheels and grinding pins are the main aim of the paper. Moreover, other possible tool's CAD design approaches are verified by application of the Python language. In this context, the study discusses selected issues of AI-assisted abrasive machining and creates the basis for the tool CAD modelling that can be used in future research also for process simulation and the machine tool parameters design. The CAD models development is crucial in terms of fast delivery of various superhard grinding wheels and pins to the final customers and it triggers further grinding process capabilities in the area of process simulation and improvement.

2. GENERAL PROCEDURE OF GRINDING WHEELS AND PINS DESIGN: COMPARISON OF TRADITIONAL AND AI-ASSISTED APPROACHES

The chapter presents a general procedure regarding design process of studied grinding tools (grinding pins and grinding wheels). Figure 1 presents two approaches regarding the tools's design procedure – a traditional and AI-assisted. Traditional design is a result of designer decisions based on the requirements of the final user of the tool and existing knowledge in the area of grinding. On the other hand, the AI-assisted design avoids traditional CAD sketching and CAD solid modelling and utilizes prompting (creation of text instructions for the LLM model). However, the prompting process requires the basic technological knowledge. The AI-assisted tool's CAD design process mainly consists of the following steps:

1. Preparation of a prompt (or several) in which assumed characteristics of a tool are defined.
2. Triggering the LLM by the prompt.
3. Importing generated code to the CAD environment (if CAD environment is used) or saving the result of the code run on the drive (if programming language is utilized solely).
4. Verification of the 3D tool model and its improvements.
5. Preparation of the CAD drawing.

The AI-assisted design does not exclude the further improvements made traditionally by using CAD tools. Moreover, it gives some opportunities for more detailed wheel modelling such as creation of diamond or CBN grains and textures. They have not been utilized so far in the standard 2D drawings due to the need for drawing simplifications and these tool characteristics have been usually described in technical specifications. Nevertheless, textures modelling is a reachable approach within the traditional CAD design. However, in the case of grains modelling, randomization of grains layout on the surface of abrasive layer or in the abrasive volume is a complicated task (i.e. time consuming). In this context AI-assisted design can automate the randomization of grain modelling within the entire tool CAD model. The detailed descriptions regarding the tools may be uploaded to the chats directly by placing them in the text or, in the case of advanced LLM commercial distributions, they may be uploaded from the separate files (text file, data sheet file, etc).

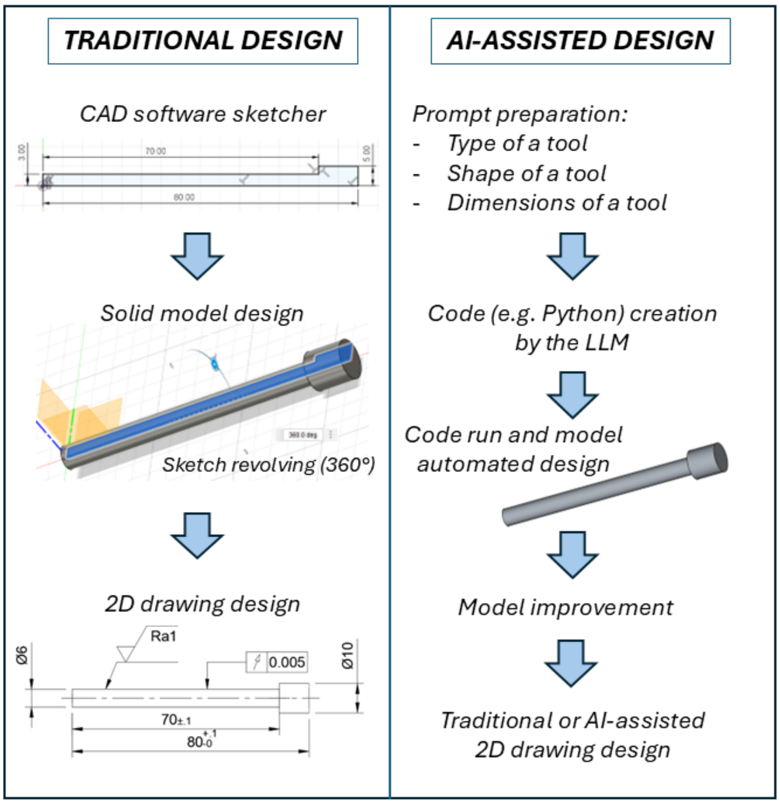

Fig. 1. Traditional and AI-assisted design approaches regarding grinding pins and grinding wheels

The traditional design is still a key element of design processes and leads to satisfactory results in most of the companies. On the other hand implementation of a tool designer-LLM communication in a form of the text instructions may be helpful for less experienced CAD users, people with disabilities, customers who do not know the details of the CAD design process and who cannot use CAD software. In this context, as stated above, the response of the chat can be copied to the appropriate CAD environment such as the FreeCAD software or the OpenSCAD software (please refer to [22]) and it can automate model creation. Moreover, the programming language such as Python and its dedicated libraries enable to directly create a CAD model without any CAD software. The abovementioned AI-assisted approach was utilized in the study and the ChatGPT™ developed by the OpenAI was used as the LLM. Nevertheless, a reader may also utilize other LLMs. Grinding wheels and pins have usually relatively simple shapes and the presented approach is a perfect application within their CAD models design worth presenting to the community.

3. RESULTS OF EXPERIMENTS FOR THE AI-ASSISTED DESIGN OF GRINDING PINS AND GRINDING WHEELS CAD MODELS

The research is based on the analysis of results of prompting and code run attempts. Two main prompts were developed in order to obtain the general geometry. The additional instructions were added in the case of texturing. The first one concerns a grinding pin and the second one concerns a grinding wheel. The geometry and dimensions of grinding tools are defined in the prompts.

Prompt 1 – for a grinding pin design:

Create a Python code that enables to design a grinding pin having diameter of a cylindrical metal shaft of 6 mm, and diameter of a cylindrical abrasive part of 8 mm. The total length of the tool equals 70 mm, while the length of the metal shaft equals 60 mm.

Correcting prompt:

Write a new code that can be implemented in the Python console of the FreeCAD software.

Prompt 2 – for a grinding wheel design:

Create a Python code that enables to design a grinding wheel having the total diameter of 150 mm, 20 mm height and the central hole having diameter of 32 mm. It shall consist of a metal cylinder and a ring. The ring shall be placed on the outer diameter of metal cylinder and this ring shall have height of the same dimension as the entire wheel, however, its thickness counted in the radial direction shall be 5 mm. The ring represents the abrasive layer of the superhard grinding wheel. Write the code that can be implemented in the Python console of the FreeCAD software.

Correcting prompt:

Create a wheel as an assembly of two separate parts, 1 – metal cylinder, 2 – ring.

The author's prompting and ChatGPT™ response (in a form of the Python code which was copied to the Python console in the FreeCAD software) enabled to design a grinding pin and grinding wheel that are presented in Fig. 2. Verification of the dimensions was performed in the FreeCAD environment and also in the Fusion™ by Autodesk [24] and it gave a positive result. The basic features and corresponding dimensions were correctly created on the basis of designer's assumptions. The abovementioned results can also be repeated for different values of diameter, hole, etc. Moreover, other tool's features can be created if their descriptions are added to the prompt.

In the next step of the study the diamond/cBN grains were also created by using the same AI-assisted design procedure. In this case, the diamond grains are represented by selected CAD primitives such as spheres, cones and cubes. If the number of grains is not very large the grains are created effectively. Figure 3 presents the grains randomly distributed on the abrasive part of the grinding pin. It is possible to create simple shapes such as sphere, cones and cubes. However, in the case of large number of grains PC hardware performance-related challenges occurred. The experiments were performed by using PC with 32 GB RAM, Intel(R) Core(TM) i7 CPU and NVIDIA Quadro (2GB) graphics. Similarly, if the ChatGPT™ was requested for a code with instructions for irregular shape of the grain, the results were not satisfactory for author's experiments at this stage of methodology development. Figure 4 presents entire CAD models of the grinding pins designed by the use of AI-assisted design procedure.

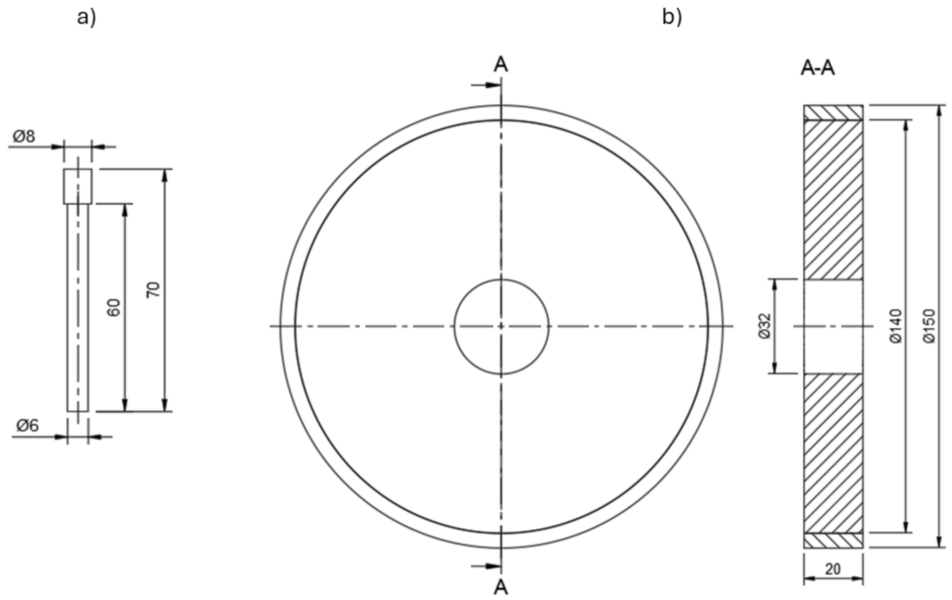

Fig. 2. CAD models created by using AI-assisted design (drawing prepared in the Fusion^{TM} by Autodesk): a) grinding pin, b) grinding wheel

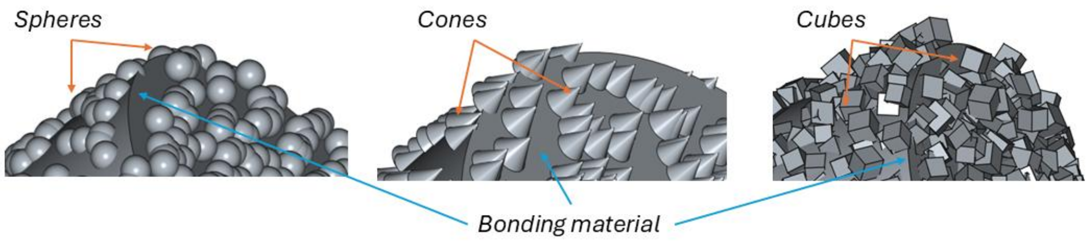

Fig. 3. Selected primitives that can be used for grinding pin diamond/cBN grains design

Fig. 4. Exemplary CAD models of grinding pins with diamond grains obtained in the FreeCAD software on the basis of Python code created in the ChatGPT^{TM} represented by spheres, cones and cuboids

Initial tests regarding basic tool geometry creation and grains distribution shifted the research attempts to another tool design needs regarding special textures on a tool's abrasive layer. Figure 5 presents exemplary textures created on the lateral surface of a grinding pin and a grinding wheel. In fact, creation of the simple textures such as axial grooves or spherical pockets is reachable and may be realized by using initial prompt with additional requests. Author also tried to achieve other textures (e.g. crossed grooves) and found it possible but more difficult to obtain by applied text comments.

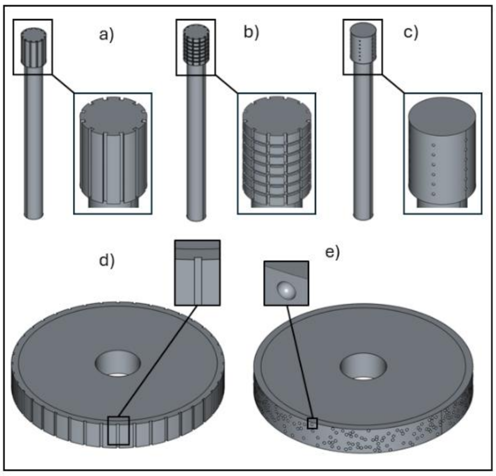

Fig. 5. Exemplary CAD models of grinding pins and grinding wheels having various textures and obtained in the FreeCAD software on the basis of Python code created in the ChatGPT™: a) axial grooves on grinding pin, b) axial and peripheral grooves on grinding pin, c) spherical pockets on grinding pin, d) axial grooves on grinding wheel, e) spherical pockets on grinding wheel

Moreover, as it is presented in Fig. 6, texture and grains may also be added together to the CAD model of a tool by using the same AI-assisted procedure. The presented tool model was developed by several correcting prompts until it has been close to authors's expectations. The process of its creation in the FreeCAD software lasted around 10 minutes after the Python code had been pasted to the Python console. However, some of the grains are still not located on the surface and are placed out of the surface ("in the air"). This example presents that in the case of complex tools characterized by various geometrical features and many grains, the process may not be as accurate as expected even if grains are modelled as simple spheres and grooves have simple rectangular shape.

Further attempts concerned grinding tools CAD models creation by the use of Python programming environment. The Visual Studio Code™ software, mentioned in the chapter, was applied to perform the Python code run and obtain the CAD model. Figure 7 presents models of a grinding pin and a grinding wheel that were automatically saved on the PC drive by using STL file format. Trimesh and numpy libraries of the Python language were used in the code generated by the ChatGPT™. In the case of STL file format the ring required on the grinding wheel is not created and tools are created as one mesh, however, the outer dimensions of the tool were verified by author in the CAD environment (in the Autodesk Inventor™ software developed by Autodesk company which is presented in [25]) and they are the same as the values required in the prompt.

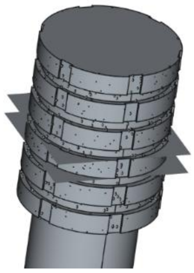

Fig. 6. Texture and grains placed within one CAD model of a grinding pin

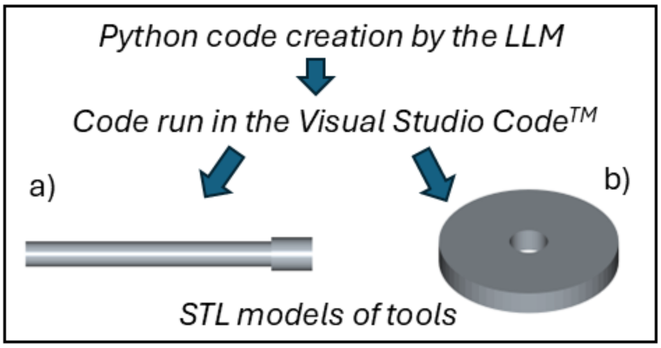

Fig. 7. STL models creation by using LLM and Python code run:
a) exemplary grinding pin, b) exemplary grinding wheel

4. DISCUSSION REGARDING THE RESULTS

Grinding wheels and pins play a crucial role in finishing processes of ductile materials and in roughing and finishing operations that concern brittle materials such as ceramics, carbides, glass. CAD modelling is a fundamental part of current tool design. Moreover, CAD modelling can be used for numerical simulations. In this context, presented results regarding AI-assistance prove that the design process can be automated in selected areas such as tool general geometry, texture and grain (using CAD simple shapes) creation, however, the properly prepared prompts are required. Moreover, in the case of presented primitives used for grain design, their orientation on the tool's surface may not meet the requirements of random cutting edge arrangement or orientation (please refer to Fig. 3) and it encourages for the future research focused on the design of grains which are similar to the real ones. In the case of simple shapes which are frequently associated with grinding wheels and pins, the AI assistance, at current stage of LLMs development, brings benefits in terms of process automation that can lead to the design process time reduction, possible reduction of the design mistakes, etc. The features of wheels and pins such as cylindrical surfaces, holes, rings, chamfers are correctly created on the basis of Python code generated by the ChatGPT™. The AI assistance changes also basic approach to the design process shifting it towards a kind of discussion-based approach with the LLM raising the possibility to improve the result manually.

Author observed also that in the case of many grains creation on the basis of Python code, some design process efficiency issues may occur. Complexity of a grinding tool and PC-hardware configuration can be responsible for that issues. The design of an external surface of the wheel may be performed in the form of one solid model, however, if all grains placed inside the bonding material are required to be designed, the multi-object assembly is required in author's opinion. Randomization of grains layout can be achieved by the use of AI support too and this process can be reached based on author's experience.

Author also tried to generate 2D technical drawings in the FreeCAD software based on the Python code proposed by the ChatGPT™ and previously created CAD models. Views can be generated automatically by using the AI-assisted approach, however, a technical drawing requires further adjustments and improvements.

5. CONCLUSION

The study presented the usability of the artificial intelligence support in the design process of grinding pins and grinding wheels CAD models. The following main results of the work can be indicated:

1. The design of a grinding wheel or a grinding pin geometries presented in the study can be supported by the generative artificial intelligence. It is possible to design the general geometry and also the elements of the grinding wheel layer such as selected textures and approximate models of grains by using primitive solids such as cone, sphere or cuboid.
2. The grinding tools design process requires geometrical data included in the prompting process and sometimes formulation of correcting prompts in order to achieve the results required by a wheel or pin designer. The observation regarding correcting prompts additionally confirms previous research results of presented references.
3. Models of the tools may be created by using Python console of the FreeCAD software or another CAD software that supports code run or may also be generated directly in the Python-based environment. However, it was observed within the study that in the case of selected grinding tool geometries and features of the grinding tools accuracy issues may occur and the final results may also differ from designer's expectations formulated in the prompts. Moreover, multi-object assemblies may require computational performance of PC-software.

It can be concluded that the presented analysis enables CAD models design and development of grinding wheels and pins detailed features and elements. However, PC-software performance-related issues were observed. In author's opinion the presented study also proves that AI has a great potential to simplify tools' CAD models design processes, however, the dedicated tool databases should be linked to the LLM models.

Proposed author's future research can be focused on further analysis regarding AI support within grinding tools design and CAD tool model-based process simulation. Moreover, other existing LLMs can be studied and different PC hardware configurations can be tested.

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Artificial intelligence usage statement and software utilization: *Artificial intelligence (ChatGPT™ (https://chatgpt.com) by OpenAI) was used to generate the Python code that was utilized in CAD environment and in the Visual Studio Code™ software (https://code.visualstudio.com). Article text and prompts were developed by author without AI assistance. Figure 2 was developed in the Fusion™ software by Autodesk (https://www.autodesk.com/pl/products/fusion-360) based on imported *.step file. Figures (from Figure 3 to Figure 7) were developed based on the print screens of models displayed in the FreeCAD software (https://www.freecad.org). Moreover, author utilized Autodesk Fusion™ by Autodesk company and FreeCAD software for creation of Fig. 1 elements. Autodesk Inventor™ software (https://www.autodesk.com/products/inventor/overview) and Fusion™ software by Autodesk company and also FreeCAD software were used for verification of dimensional correctness of the obtained CAD models.*

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