New Trends of Mineral Composite Application in the Production of CNC Machine Tools

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Abstract – The presented article is based on the fact that the manufactured CNC machine tools are based on long-known design solutions, in which the main production material is steel. Based on the fact that the discovery of the composite material in science and technology opened up the hitherto unexplored application possibilities of this new technical material, the scientific question arose whether these materials can be used as a structural element of production machines and what are the advantages or disadvantages of such a solution. The Introduction of this article is devoted to the issue of composite materials, specifically mineral composites, technical and economic specifications. The main part of the article provides an overview of current trends in manufacturing technologies of CNC machine tools components.

Keywords – Mineral composite, CNC machine tool, production process.

1. Introduction

At present, composite materials are coming to the fore. These materials are part of technical progress and bring new applications to composite materials whose properties are the same or better than those of commonly available materials.

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The development and investigation of the properties of these new materials require interdisciplinary cooperation. This also applies to mineral composite materials. They offer indisputable advantages compared to conventional construction materials that have been used in the past in the construction of CNC machine tools. This article maps new trends in the field of mineral composite materials, focuses on their properties and possibilities of use in the production of CNC machine tools. [1]

The material of two or more substances with different properties, which together give new properties to the final product new, is generally a composite. One of the most famous composite materials is reinforced concrete, laminate or polyester. A frequently used composite is an asphalt mixture for the production of road surfaces. [1]

Composite materials are polyphase materials produced by an artificial combination of different materials that are chemically and physically different. The resulting material that is created achieves such properties that its components cannot achieve alone. An example is a lightweight composite that acquires its properties by inserting continuous carbon fibres in one or more directions into a polymer matrix. The fibres provide strength and stiffness to the composite and the polymer matrix serves as a binder. Another well-known example of composite material is, for example, concrete. This is obtained by mixing cement, which in this case is a matrix with sand and gravel. In general, composite materials are classified according to the type of matrix. The matrix is the material by which the fibres in the composite are joined. The main task of the matrix is to guarantee the geometric position of the fibres and the dimensional stability of the product, to protect the fibres from external influences, to transfer forces from fibre to fibre. The matrix as a composite reinforcement should be characterized by low weight and good plasticity. It should ensure good wettability of the surface of the fibre and should not chemically react with the fibres at high temperatures. [2]

2. Mineral Composite – Specification of Properties

A mineral filler of various grain sizes and a matrix based on epoxy resin form a two-component material called a mineral composite. Epoxy resin, not cement, serves as a filler in this type of concrete. Due to greater run-in and compaction, mineral composite products made at room temperature by casting into detachable moulds are placed in vibrating moulds. There is no external heat supply during the production of the composite casting.

Figure 1. Example of mineral composite material [3]

The curing process is based on an exothermic reaction, where the casting is heated to a maximum temperature of 60°C. The casting is ready to be removed from the mould after a few hours and the final hardening takes place one week after casting. [3]

Up to 80% of the volume of the mixture consists of a filler of various grain sizes (0-16 mm) and, together with the degree of compaction, affects the quality and the resulting structure of the mineral composite. The mechanical conditions that the filler has to meet include tensile and compressive strength, Young's modulus, heat capacity and thermal expansion. Mineral materials used as filler are granite, basalt, silica, basalt, mica and feldspar. Filler additives - small particles up to 1 mm in size - are used for better processing of the mineral composite and filling of the pores. Composite materials consist of from mineral and non- mineral mixtures. These additives include glass, grey cast iron, steel. The use of Fuller and Thompson grain size curves determines the optimal mixture of composite materials, i.e. the mineral composite must have a solid structure with the largest possible grains to achieve the best mechanical properties. [4]

Figure 2. Liquid resin classification for mineral composite [4]

The maximum grain size is affected by 5-8 multiple of the maximum grain size, shape and size of the casting. The filler has two components and consists of epoxy resin and hardener. In the total volume, the amount of filler is directly proportional to the degree of compaction and the proportion of

filler should be as low as possible to achieve optimal mechanical properties. In practice, this makes up the remaining 20%. Epoxy resin is the most commonly used filler. It is characterized by low viscosity, which is a good prerequisite for good liquidity of the mixture, chemical and mechanical properties of the

mixture, sufficient time for the workability of the mixture and slow curing. At a temperature of 75 ° C, the epoxy resin loses its mechanical properties, i.e. the mineral composite castings are not usable in operations with a temperature higher than 75 ° C. Properties of mineral composites dependent on manufacturing technology, joining agent and filling material. [5]

3. Technical and Economic Parameters of Mineral Composite

The quality of the machined surface and the tool life is increased by up to 30% by using castings made of mineral composite, which dampens vibrations and shocks eight times faster than castings made of grey cast iron. The size of the vibration amplitude and the noise of the machines is reduced by 20% due to the dynamic properties of the composite. The heat generated during the production process has a great influence on the quality of the machined surface and the tool life. Heat sources can be internal or external. Internal include hydraulics, lines and motors, and external include air circulation and temperature gradient. Due to the low thermal conductivity and high heat capacity, mineral composite castings do not react to short-term temperature changes. As a result, the accuracy of production machines or manufactured workpieces is higher. The mineral composite is not subject to corrosion, which reduces the cost of surface treatment compared to conventional production machines, and it is also resistant to conventional coolant emulsions, lubricants, hydraulic oils and dielectrics. In contrast to steel and grey cast iron, the production of composites takes place at room temperature, i.e. around 20 ° C without any external heat supply. The production of mineral composites reduces energy costs by 20 - 40%. The declining machining costs are due to low internal stress and minimal contraction of the mineral composite, which allows the production of the casting with final precision. In practice, grinding of only functional surfaces is used to achieve the required tolerances. The mineral composite has low stiffness and strength compared to steel and grey cast iron. These properties are compensated by the corresponding wall thickness of the mineral composite and lead to a higher casting weight through the low density of about 20% [6].

4. Application of Mineral Composite in the CNC Machine Tool Production Process

Mineral composite castings are specially dimensioned according to the rules, as are castings made of grey cast iron and welded steel construction. The first step is to design in 3D CAD software. The

next step is to calculate the deformations using the Finite element analysis method and optimize the casting. The dimensioning and design of the mould takes place simultaneously with the construction of the casting. High acquisition costs are caused by high demands on the rigidity and quality of the mould, which are placed on the accuracy and quality of the cast surfaces. Other important aspects include the implementation of a prototype part and the time required for construction. The approximate length of the design and optimization of the casting takes approximately four weeks, depending on the complexity and size, and since the design of the mould takes place in parallel with this design, it takes another three weeks after the final approval of the casting. It takes 8-10 weeks for the actual production of the mould to take place, and it takes about 1 week to cast and inspect the prototype. Depending on the size of the casting and its complexity, the time is around eight weeks from the approval of the material, production and inspection of the prototype. The places or areas where it is necessary to achieve the highest precision of the casting are placed on the base plate, i.e. on the stiffest place of the mould. The shape of the mould is determined by the basic shape of the casting designed from simple planar elements. The base plate is the base for the front and sidewalls. On the upper side of the mould, there are folders - bridges that reinforce the mould. The functional parts of the casting include electrical and hydraulic lines, guide rails, threaded inserts, steel bushings and plates, which are attached to these plates. For relief, resp. plastic pipes and polystyrene cores are used to reduce weight. Attention has to be paid to different material characteristics, such as stress and thermal expansion, due to the use of integrated functional parts made of grey cast iron and steel such as guide and mounting rails. By using precise jigs in a room with an air temperature of approx. 23°C, higher accuracy of functional surfaces is achieved by machining or subsequent casting. A contribution to the design variability is the alternative of joining individual parts by glueing. A mixture of a mineral composite with corresponding grains of a certain size and proportion of epoxy resin is used as the adhesive. Defects caused by damage to the casting can be eliminated by glueing or subsequent casting while maintaining the mechanical properties. Damage means cracking of the casting, scratches or bounced corners. High demands are placed on the design and production of a prototype or a mould of a mineral composite casting. Possible design changes that cause a change in the mould during series production lead to substantially high additional casting production costs. [7]

Figure 3. The manufacturing process of mineral composite machine bed [7]

Wax is sprayed on the cleaned surface before the mould is assembled, when after its drying a two-component polyurethane varnish (0.2 mm) or so-called Gelcoat (0.5-2 mm). This varnish allows the casting to be removed from the mould without any complications and also serves as the base colour of the product. The integral functional parts are cleaned and degreased, which ensures perfect adhesion. The individual modified parts are attached to the boards, which are then assembled and attached to the vibrating table. The mixture of the mineral composite is cast into the already prepared mould, processed in a mixing device. Initially, the fillers and binders are mixed separately and finally, they are mixed. The resulting mineral composite is cast into a prepared mould using a vessel. During casting, the mineral composite is compacted by vibrations according to predetermined parameters, i.e. frequency, amplitude, to achieve a compact structure. Due to the exothermic reaction, hardening takes place after casting, when the casting is heated to a maximum temperature of 60 °C. The hardening time of the casting depends on its size and ambient temperature. The casting, considered to be medium-sized, weighing approx. 2500 kg, is cast for approx. 100 minutes. Removal from the mould is only possible after eight to twelve hours after casting. Functional surfaces can be machined only after the final hardening of the casting, and thus after 6-8 days. [8]

Figure 4. Mineral composite bed [8]

Mineral composite machine tool beds are a productive basis for machine tools. Machine tool beds made of this type of polymer concrete increase speed and accuracy during milling. Higher vibration damping and reduced noise levels without compromising production accuracy are tested in testing machines compared to steel or cast iron. In terms of dimensional and shape accuracy of production and increasing machining speed, there are currently requirements for machine tools.

Figure 5. Illustration of machine tool bed made of mineral composite

Machines using mineral composite for the machine tool bed have an advantage on world markets due to a large number of industry requirements for machining accuracy. Great importance is placed on the dynamic behaviour of the machine with increasing spindle speed and increasing accelerations on the sliding axes. Faster feeds, quick tool changes and short positioning times are the basis for fast machining, which leads to an increased dynamic load on the machine as a whole and in its parts. The mineral composite is characterized by up to a tenfold increase in the ability to dampen vibrations compared

to steel and cast iron and also reduces the noise level (by about 20%). Mineral composite parts are produced by casting in precision moulds at a temperature of only 45 ° C. With this type of technology, it is possible to produce machine tool parts with high precision and with the appropriate functional metal elements. [9]

5. New Trends in Manufacturing Technologies of CNC Machine Tools Components

The basis of the conceptual solution of machine tools is the analysis of their supporting frames, which has to have sufficient rigidity with high natural frequencies and high vibration damping ability. When choosing the material of the machine, however, it is necessary to take into account other aspects, namely production and economic. [10]

At present, various engineering approaches and scientific analyses are used in conjunction with consultations of practical requirements to ensure the creation of the most suitable concept of CNC machine designed for machining special parts of moulds, which are produced by direct metal laser sintering technology from powdered tool steel. One of the possibilities is the implementation of CA systems within the design solutions for the creation of a composite machine tool bed for special CNC machines. The created solutions can be subjected to various engineering analyses using CA systems, their basic mechanical properties can be determined. The following figures show examples of the implementation of these approaches.

Figure 6. Design solution of machine tool bed from a mineral composite material by CA system application

Figure 7. Example of machine tool bed analysis by CA systems application

The machine tool bed is a relatively complex structure of bodies, mechanisms and components that are movably or immovably connected, which closes the flow of forces during machining and which affect the static and dynamic rigidity of the machine - tool-workpiece system at the machining location. The load-bearing structures of the machines are subject to high static and dynamic rigidity, sufficient vibration damping and resistance to self-excited oscillations, small thermal deformations, time stability of the shape (without internal stress in the bodies), long service life and production economy. When designing the main bodies of the machine support system, it is important to choose the right materials from which the body will be made. This choice is influenced by several factors:

- the properties of the building material (strength, specific weight, modulus of elasticity, internal stress, thermal expansion, specific heat, thermal and electrical conductivity),
- production factor (material machinability, joining of individual parts, production technology - casting, welding),
- economic factor (number of produced pieces, price).

6. Conclusion

Requirements from manufacturers result in the development of new innovative materials, taking into account the technical and economic aspects placed on them. This means the development of materials with a good required property/price ratio. This is directly related to the composition of the material and production technology. One of these materials is also

a mineral composite. Thanks to its properties, the composition of the materials used, the production process and the price, it has found application in technical practice. This article provides a comprehensive view of composite materials based on mineral composites, the method of production including individual parts of machine tools, the used technologies and their application in engineering.

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