Design of Bed Machine for Machine Tool Based on Polymer Concrete Mixtures

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Abstract **– The competitive struggle among companies is steadily increasing, which in turn increases the demand for innovative technologies, but such technologies, which do not increase the production costs of the company and, if so, to a minimum. The solutions for innovation and production efficiency are solved individually by companies, based on the production method, the technology used or the type of products. One possible solution is to co-work with subcontractors to provide companies with semi-finished products for further processing for a specific product. The introduction of innovative processes, technologies and materials will help to combat competition, but on the other hand, such a solution may not match with the design of individual components and machines. Deficiencies may be manifested in the form of insufficient material properties or requirements for safety mechanisms. This paper deals with the design of a bed machine for a machine tool and its individual parts, which will be made of polymer concrete.**

Keywords **– Polymer concrete, Machine bed, Machine tool, Design.**

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1. Introduction

Composite materials can be defined as materials that are composed of several components, differing in physical and chemical properties, which by their combination form a compact heterogeneous system. Newly formed materials have specific properties that cannot be achieved by any component alone. The strength of these materials can be compared with the strength properties of metals. The elastic properties, in turn, give the material a high degree of flexibility. Compared to conventional materials, polymer composite materials are not only characterized by excellent mechanical properties but mainly by their low weight and cost. An excellent example of a damping, thermal stability, and wide structural variability composite is polymer concrete.

Polymer concrete is one of the most commonly used materials and ranks among particulate composite materials. Polymer concrete is used to produce castings weighing several kilograms up to several tons, offering a wide range of applications. Nowadays, mainly bases for machine tools and measuring machines are made of polymer concrete, which is used in engineering, electrotechnical, food and chemical industries.

2. Composite Materials

Composites are materials which are artificially created and made from two or more components. Each component has different physical or chemical quality properties, which stays separate and different also in the final structure. Each composite material is created of a matrix and reinforcement (Fig. 1). Each of these components has to be present in the mixture. The reinforcing materials are surrounded by matrix material which supports them by maintaining their relative positions. Reinforcements have special mechanical and physical properties that are used to improve matrix properties. Synergism creates material properties that are not available from the individual components. By combining the variability of available matrices and reinforced materials, we can achieve incredible design potential. [1]

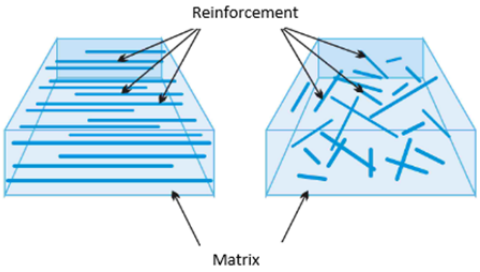

Figure 1. Illustration of composite components [1]

Composite materials are materials that have been created by physically combining existing simple materials. The matrix has the function of a binder. The second component, the intermediate phase, serves as a reinforcement which has a reinforcing effect. [2]

In particular, the following parameters affect the properties of a composite composed of component A (matrix) and component B (reinforcing component) [2], [3]:

- The volume fraction of individual components of the composite,
- System geometry
  - unidirectional continuous phase (rods, fibres),
  - two-dimensional continuous phase (plate, plate),
  - three-dimensional continuous phase (spatial network),
- Degree of continuity - from complete continuity to the phase is divided into discrete particles (this division also allows the systems "matrix - dispersed particles of secondary phase" (eg. perlite, sorbit) to be understood as composite materials and creates a transition to classical materials)
- Phase alignment (extremes are parallel and serial alignment)

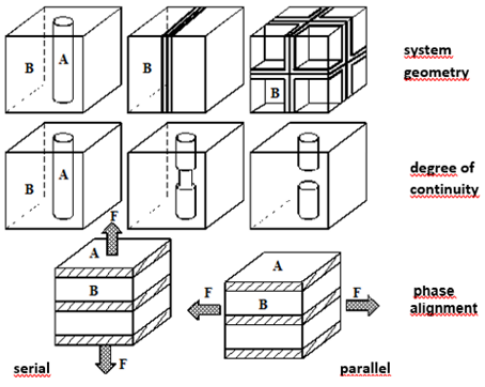

Figure 2. Characteristic parameters of composite materials [3]

The mechanical arrangement of the composite is influenced by the phase arrangement. The properties of the composite can be considered addictive and can, therefore, be derived from the properties of the starting components. When loading a parallel model, the condition of the same phase deformation has to be fulfilled, while the stresses transmitted by the phases will be different, while in the serial model the phase voltage will be the same (but different deformation). [4], [5]

Based on the above, the following modules can be derived:

- modulus of elasticity of parallel model

$$E_p = E_A \cdot V_A + E_B \cdot (1 - V_A) \quad (1)$$

- modulus of elasticity of series model

$$E_s = \frac{E_A \cdot E_B}{E_A \cdot (1 - V_A) + E_B \cdot V_A} \quad (2)$$

The modulus of elasticity of a composite with a series arrangement is always lower than that the parallel, and more flexible phase has a decisive influence on the modulus of elasticity. In fact, in most cases, the arrangement is not ideally parallel or series and the composite modulus values lie between the values for E_p and E_s [4], [5].

Polymer matrices, often called resin solutions, are most commonly used in the manufacture of composite materials. We can divide them into several categories; the most commonly known as polyester, vinyl ester, phenol, polyimide, polyamide, polypropylene, PEEK and others. The materials used as reinforcement are often fibres, but also ordinary ground minerals. These are materials that are formed by combining the reinforced material (filler) and the macromolecular substance, mostly to improve mechanical properties. The polymer component forms the basic continuous matrix of the composite. The filler is a non-volatile additive of both organic and inorganic origin. One suitable example of composite material is concrete, which is mainly composed of cement and gravel. The cement forms a matrix and gravel is reinforcement [6].

3. Composite Materials Based on Polymer - Concrete Mixtures

The polymer-concrete is composed of three components, the ratio of the individual components affecting the resulting properties of this composite material. [10] For the production of polymer-concrete products, demountable moulds are used, which are filled by casting technology. The whole process is carried out on vibration tables to improve compaction. Subsequently, the solidification process takes place, an exothermic reaction in which the

material is heated to a maximum of 50°C to 55°C [11], [12].

Polymer-based composite materials can generally be categorized as follows [7]:

- Porous materials impregnated with polymers
- Macroscopic composite materials
- Reinforced polymers

Composite materials can be divided according to different sorting parameters. Most often we can see the division of composite materials according to [8],[9]:

- sizes containing fibres
    - macro-composites - have reinforcement with a cross-sectional size of 1 - 100 mm, the most common use is in the construction industry. The most important macroscopic composites are laminates in which the macromolecular substance forms a macroscopic continuous phase.
    - micro-composites - the range of transverse reinforcements is from 1 to 100 μm. Compared to metal and their alloys, the micro-composite materials have a lower density, thus a favourable ratio of tensile strength, resp. modulus of elasticity to density
    - nanocomposites - composite materials that have a dimension of reinforcement in nm.
- secondary phase (Fig.3)
    - composite materials with particulate reinforcing phases
    - composite materials with reinforcing fibres,
    - laminated composite materials
- metal phase composite materials,
    - composite materials with glass phase,
    - Ceramic phase composite materials,
    - fibre-reinforced composite materials

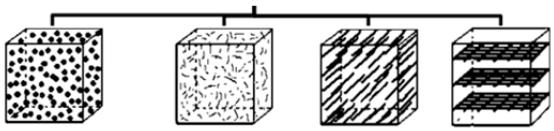

Figure 3. Division of composite materials according to the shape of the second phase [9]

The properties of the polymer-concrete strongly depend on the preparation conditions. For a given polymer-concrete type, the properties depend on the binder content, the size of the aggregate, the curing conditions and the like. [14] Below are the basic physical properties of polymer-concrete. Among the important properties of polymer concrete belongs the following - temperature stability, modulus of elasticity and damping abilities. [13]

Table 1. Comparison of polymer-concrete properties with other materials [8]

Properties	Units	Steel	Grey cast iron	Polymer concrete
Density	g/cm^3	7.85	7.2	2.1-2.4
Compressive strenght	N/mm^2	250-1200	350-450	140-170
Bending strenght	N/mm^2	400-1600	150-400	25-40
Young´s modulus	kN/mm^2	210	80-120	30-40
Heat-transfer coefficient	W/(m*K)	50	50	1.3-20
Thermal expansion coefficient	Um/(m*K)	12	10	12-20
Specific heat	kJ/(kg*K)	0.45-0.5	0.5	0.9-1.3
Logarithmic decrement		0.002	0.003	0.02-0.03
Cost	EUR/dm^3	7.67	5.11	2.56
Manufacturing energy demand	MJ/dm^3	160	120	25

4. Model Design for Machine Tool

The functional surfaces of the casting, i.e. the surfaces where it is necessary to achieve the highest possible accuracy, are placed at the strongest points of the mould - the base plate. The basic shape of the casting is designed from simple planar elements, which also determines the shape of the mould.

Interior spaces designed to reduce casting weight or function can only be created by specially manufactured parts. As a general rule, the minimum wall thickness of the cast parts is set at 5-8x the largest filler fraction. The thin walls in the upper region of the casting can be cast additionally from the mixture with finer fractions than the casting of the base plate. Depending on the type and size of the mould, a 5° bevel, ± 2° is required for mould removal. Unlike cast iron, different thicknesses of the casting with steep transitions are allowed because the internal pressure of the polymer concrete is negligible. Also, the ribs characteristic of cast iron is not required. [15]

For economic and feasible reasons, the number of fixture types should be kept to a minimum, so most

large manufacturers offer only three standard types: [16]

- threaded bushings,
- carrying brackets,
- boards for attaching the board or pedestal to the floor.

Autodesk Inventor software was used to design the machine tool base. The machine tool plate was designed from a composite material based on polymer-concrete mixtures, which has excellent damping and strength properties.

Figure 4. Plate base

In order to fix the machine to the plate, it was necessary to design inner sleeves (Fig. 5) which extend along with the whole material which will be inserted into the polymer-concrete frame during its production, during casting into the mould.

Figure 5. Inner case

Threaded feet (Fig. 6) are also used to support the frame stability and are also height-adjustable, mainly due to possible surface irregularities. Feet are located on the bottom of the plate.

Figure 6. Threaded feet

Figure 7 shows the final model design for a machine tool. The plate itself also has a recess in the central part of the plate, and the arched recess extends also on the front and back of the plate. The recess serves to relieve the material.

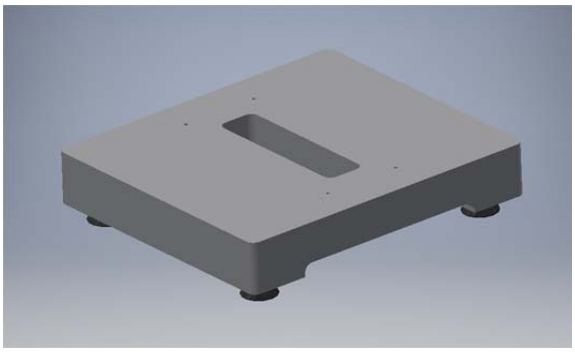

Figure 7. Model for machine tool base

5. Conclusion

This paper is focused on the application of composite material based on polymer - concrete mixtures on the construction of the machine tool support system. It also describes design principles for designing a machine tool base. The article shows a specific model that was created in Autodesk Inventor software. In addition to the final model, the article also shows its individual components. Polymer concrete is one of the most commonly used materials and ranks among particulate composite materials. Polymer concrete is used to produce castings weighing several kilograms up to several tons, offering a wide range of applications. Nowadays, bases for machine tools and measuring machines are used mainly in the machine, electrical, food and chemical industries.

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References

[1]. Campbell, F. C. (2010). *Structural composite materials*. ASM international.

[2]. Bernasovský, P., Blecha, A., Bošanský, J., & Magula, V. (1996). *Náuka o materiáli a zvariteľnosť ocelí*. WELDTECH.

[3]. Sičáková, A. (2011). *Vybrané kapitoly z kompozitných materiálov*. Stavebná fakulta TUKE.

[4]. Martinkovič, M., Hudáková, M. & Romančík, M. (2001). *Náuka o materiáloch II – návody na cvičenia*. Vydavateľstvo MtF STU v Trnave.

[5]. Ehrenstein, G. W. (2009). *Polymerní kompozitní materiály*. Scientia.

[6]. Chawla, K. K. (2012). *Composite materials: science and engineering*. Springer Science & Business Media.

[7]. Bareš, R.A. (1988). *Kompozitní materiály*. Praha: SNTL, 1988.

[8]. Mráz, P., & Talácko, J. (2006). *Konstrukce strojů s kompozitními materiály*. Nakladatelství ČVUT.

[9]. Yin, J., Zhang, J., Wang, T., Wang, W., & Ren, X. (2015). Mechanical properties optimization of resin mineral composite for machine tool bed. *Journal of Reinforced Plastics and Composites*, *34*(4), 329-340.

[10]. Erbe, T., Król, J., & Theska, R. (2008, October). Mineral casting as material for machine base-frames of precision machines. In *Twenty-third Annual Meeting of the American Society for Precision Engineering and Twelfth ICPE*.

[11]. Taha, M. R., Genedy, M., & Ohama, Y. (2019). Polymer concrete. In *Developments in the Formulation and Reinforcement of Concrete* (pp. 391-408). Woodhead Publishing.

[12]. Reddy, S. V. B., & Santhosha, V. (2018). Experimental Study on Fibre Reinforced Polymer Concrete. *International Journal of Applied Engineering Research, 13*(15), 11844-11856.

[13]. Mitalova, Z., Simkulet, V., Zajac, J., Radchenko, S., Radic, P., Olexa, I., & Litecka, J. (2017). Surface quality of Wood Plastic Composite material after machining. In *2nd EAI International Conference on Management of Manufacturing Systems* (p. 125). European Alliance for Innovation (EAI).

[14]. Jafari, K., Tabatabaeian, M., Joshaghani, A., & Ozbakkaloglu, T. (2018). Optimizing the mixture design of polymer concrete: An experimental investigation. *Construction and Building Materials, 167*, 185-196.

[15]. Harničárová, M., Valíček, J., Kušnerová, M., Kmec, J., Palková, Z., Kopal, I., Krmela, J. & Panda, A. (2019). Study of the influence of the structural grain size on the mechanical properties of technical materials. *Materialwissenschaft und Werkstofftechnik, 50*(5), 635-645.

[16]. Sadilek, M., Fojtík, F., Sadílková, Z., Kolařík, K., & Petrů, J. (2015). A study of effects of changing the position of the tool axis against the machined surface. *Transactions of FAMENA, 39*(2), 33-46.