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CEMENT-BOUND MINERAL CASTED PARTS IN PRECISION ENGINEERING

Christoph Hahm[1], Torsten Erbe[2], Rene Theska[1]

[1] Ilmenau University of Technology, 98693 Ilmenau, Germany
[2] ASML BV, 5504 DR Veldhoven, The Netherlands

ABSTRACT

The design of a machine frame, supporting a plurality of components/modules, is a major challenge during the development of precision systems. The geometric stability of the supporting parts under thermal and mechanical loads has a decisive influence on the achievable accuracy. Common materials like cast iron or natural stone have preferable properties but often come with high costs and long lead times due to sourcing or manufacturing process and required geometric precision.

Concrete is an interesting alternative. Polymer concrete and cement-based concrete such as self-compacting concrete have been considered as cost-effective alternatives for quite a while now. This paper summarizes recent research and findings on these alternative materials and reviews their applicability in machine frame design. Aspects of the cold primary shaping process will be covered with an emphasis on ready-to-use features with geometric tolerances in the order of magnitude of micrometers. The potential for integrating functional elements is discussed. The advantages of concrete as an alternative material are summarized with regard to the application of the design principle "functional material at the location where functionality is required".

1. INTRODUCTION

The automated fabrication of many of today's ubiquitous products, such as cell phones or smart watches, etc. requires handling and positioning with a precision previously reserved for high-end applications such as coordinate measuring machines or even lithography equipment. With the increase in complexity and the growing number of functionally integrated products, the demands on tooling and assembly equipment are growing too. The ability to accurately manufacture and handle products with micrometer precision in working areas in the order of magnitude of meters is therefore essential for competitiveness.

Consequently, suppliers of machinery and equipment are faced with the challenge of reducing unit costs and delivery times while facing increasingly customer-specific requirements. Machine frames, which - in relation to the overall system - often have a huge mass, many precise features and are made of specific materials, are a major source of material and material overhead costs as well as long lead times. They will therefore be the subject of this paper.

One way to reduce delivery times and costs for machine frames is to use concrete instead of traditional materials such as natural stone, cast iron or welded steel structures [e.g. 1, 2]. The benefits of using concrete[1] for machine frames has been discussed since a long time [3-13]. However, despite the extensive and broad investigations the number of publications reflecting the state-of the art is limited. Existing articles, books, and publications by companies involved

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[1] The distinction between polymer- and hydraulic-concrete will be explained in chapter 3. If not specifically distinguished the term concrete refers to both.

in concrete for machine applications address relevant topics. But they are either not current or focus only on specific aspects of a particular material type [14-23] or the applications [6 and 24-34]. The goal of this review article is to close this gap by providing a comprehensive overview by discussing the various aspects relevant for the use of concrete for machine frames and summarizing the properties of concrete as known so far.

The article is divided into three main parts. First, the general requirements for machine frames and their impact on material selection are briefly discussed with special emphasis on concrete-related aspects. Starting from these basics, polymer and hydraulic bound concrete and their properties are considered more in detail. Finally, the effects of the properties on the precision of machine frames as well as those on lead time and costs are discussed.

2. GENERAL REQUIREMENTS OF MACHINE FRAMES

Machine frames are essential components in precision applications, providing the stable base for accurate and reliable performance of machine functions. High demands are placed on structural integrity, vibration minimization and thermal stability. Machine frames represent the interface between the installation environment and further components of the machine. They are exposed to internal and external mechanical and thermal loads.

https://www.studer.com/de/rundschleifmaschinen/rundschleifen/product/s141/#image-gallery-1

Figure 1: *Machine frame part of a grinding machine made from polymer concrete with metal inlays and precision linear axis a as technology example [35]*

A large number of interfaces at a machine frame serve not only to support mechanical forces but also to realize material, energy and information flows. Examples include those for support feet, media supply lines, cables, hoses and/or their supports, drive systems, measuring systems and scales as well as guide ways and/or bearings for moving parts.

Guides and bearings often place the highest demands on form and position tolerances as well as on the rigidity of the design. Since the machine frame often directly incorporates precise guide surfaces (e.g. for aerostatic guides) or mounting surfaces for bought-in guideways, (e.g. rolling element guides), it directly determines the accuracies of motion systems within the precision systems.

In this contribution, the design study of a precision linear axis, as exemplified in Figure 1, with the particular focus on air bearing guideways is used as an application example to compare different approaches. Although this paper deals with machine frames for precision mechanical applications, it should be noted that the same precision requirements apply to moving parts such as machine tables. Especially for machining and measuring applications involving workspace volumes of 1 m^3 and more, concrete is an interesting material option.

2.1 Precision features and stability of machine frames

It is hardly possible to quantify general requirements for machine frames since they vary depending on the application. As an example, with tight requirements, a machine frame with integrated guide surfaces for an aerostatic guide as used e.g. in coordinate measurement machines is considered. The following values are assumed (inspired by [36]):

- flatness of 2 $\mu m/m^2$,
- straightness of 1 µm/m
- angular deviations 10 arcsec.

The realization of a machine frame with this precision requires the careful consideration of aspects of manufacturing, transport, installation and usage into the design. To ensure the required accuracy over the entire operating period, all operating modes and life phases with their associated specific loads must be taken into account, which is usually supported by a FE analysis. Loads in this context are the forces and their variation, temperatures and their gradients during operation, transport, etc. Static loads from 1 kN to >>10 kN, external and internal excitations with frequencies from 10 - 4000 Hz at working temperatures of 20 ±5°C and transport temperatures between 0 and 60°C can be expected.

A detailed knowledge of the material properties is required. The tight tolerances require specific production measures and means (traditionally grinding, lapping).

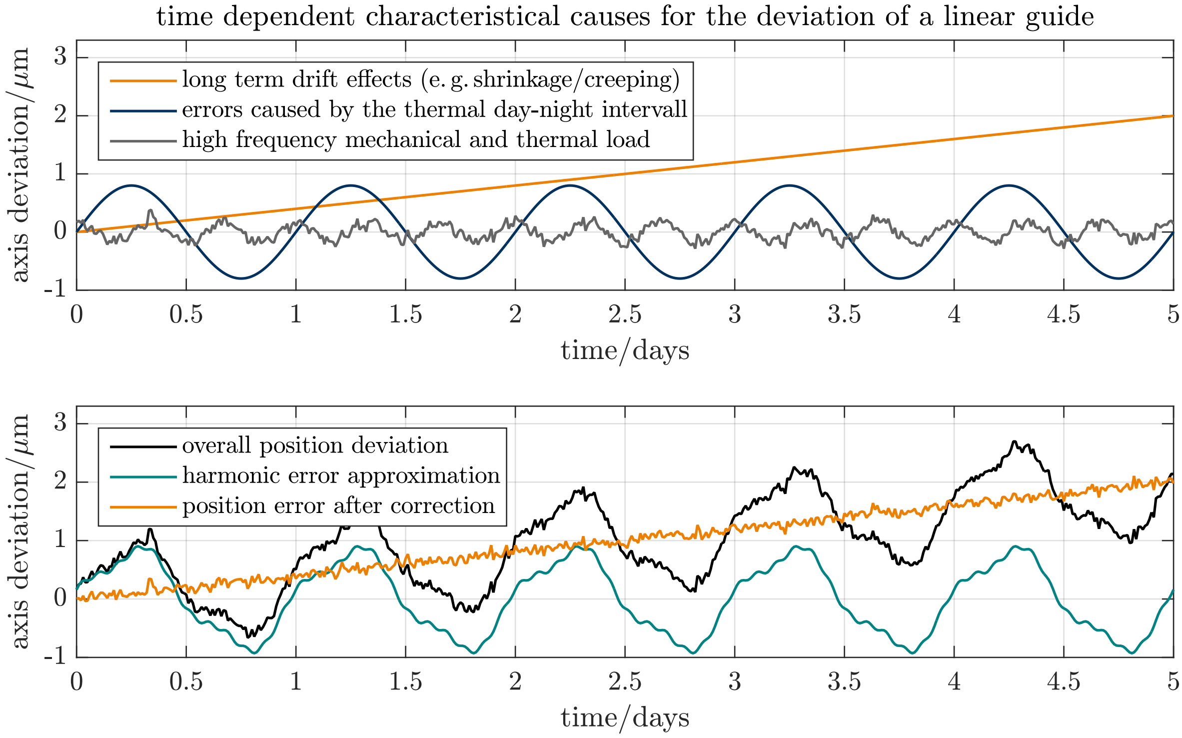

Figure 2: *Symbolic position deviation at machine frame due to different loads and influences exemplifying different time constants and the influence of different averaging periods*

The term stability is often understood as the constant relative position with respect to reference features over time. This can be interpreted primarily as stiffness against mechanical or thermal loads. Therefore, the design of machine frames aims for low strain - and thus low stress - resulting in large load bearing cross sections and profiles. This results vice versa in the desire for a low coefficient of thermal expansion.

Since an infinite stiffness cannot be realized, other ways need to be found. To be able to minimize the effect on the function by compensation or correcting measures (see Figure 2), a predictable and reproducible behavior is required.

2.2 Materials used for machine frames

The range of materials used for the production of machine frames is remarkably unchanged since decades. Only a few materials allow static and dynamic stiffness as well as cost-effective precision manufacturing of large (>> 1 m^3) machine frames. Table 1 shows the ranges of properties of a selection of common materials together with polymer, hydraulic bound and self-compacting (SCC) concrete.

Table 1: *Properties of materials commonly used for machine frames. Note values are only indicative.*

Property [unit]	Steel[1]	Cast iron[1]	Al_2O_3 Ceramic[2]	Natural Stone		Standard concrete[4]	SCC[4]	Polymerc oncrete[4,5]
				Granite[3]	Gabbro[3]			
Young's modulus [GPa]	209… …211	88… …185	350… …410	60… …95	109	22… …35	45	30… …45
Density [g/cm3]	7.85	9.5… ...10.5	3.7… …3.9	2.8… …3,0	2.9	2.0… …2.8	2.5	2.3… …2.4
Specific Young's modulus [kNm/kg]	26,6… …26,9	9,3… …17,6	94,6… …105,1	21,4… …31,7	37,6	11,0… …12,5	18,0	13,0… …18,8
Compressive strength [MPa]	260… …850	720… …1150	2500… …4000	140	215	55	110	100… …180
Bending strength[6,7] [MPa]	300… …600	290	310… …630	14*	22*	2.6… …18	7.7… …8.1	14… …30
Thermal expansion [ppm/K]	11… …17	9.5… …10.5	0.9	7.5	5.4	6… …14	9.7… …10.6	15… …19
Specific heat capacity [kJ/KgK]	0.45… …0.5	0.46… …0.63	0.9	0.79	0.88… …1.13	0.9… …1.0	1,0	0.7… …0.9
Thermal conductivity [W/mK]	46… …58	47… …50	25… …36	3	1.6… …4.0	1.7… …2.1	1.9… …2.2	1.0… …2.9
Logarithmic decrement	0.002	0.003	0.001			-[8]	≤ 0.25 [8]	0.01… …0.1 [8]
Source:	[37]	[37, 38]	[39]	[40, 41]	[40, 41]	[42]	[3]	[3], [9], [38], [43]

[1] … There is not one specific steel and cast-iron type used for frames, properties are very depended on alloy type, heat treatment, conditioning etc. and therefore given in ranges.

[2] … Properties of ceramic are individually dependent on the production method.

[3] … Properties of Gabbro as a subtype of natural stone is as all types of natural stone subject to natural fluctuations.

[4] … Standard concrete properties – despite well regulated (e.g. DIN 1045–2 [60]) – depend on grain fractions and the materials used. Properties can be "tuned" to a decent extend by using specific fillers, binders and their respective ratio.

[5] … Properties of polymer concrete depend on grain fractions and the materials used.

[6] … Assuming that bending strength is similar to tension strength.

[7] … Bending strength properties of anisotropic materials depend on type of testing (3-point or 4-point bending test) therefore they may vary in literature.

[8] … The damping properties of concrete are depended on the aggregates used which is extensively investigated in civil engineering. The contributions [44] and [45] are mentioned here only indicative, referencing specific publications about this topic.

By comparing the selection of properties in Table 1 it becomes obvious, that metal and ceramic materials showing far higher strength values than natural stone and concretes. Since the design rational is driven by stiffness (not strength) a high specific Young's-modulus is an important criterion for material selection. Due to a specific Young's-modulus better than steel and cast iron and a better machinability compared to ceramic materials, natural stone, in particular gabbro, is a favorable material for machine frames. Furthermore, low thermal conductivity and expansion as well as high specific heat results thermal low pass filtering behavior.

Anyhow, with specific strength values close to those of granite, a CTE comparable to steel, excellent material damping, and the option of primary shaping of complex structures with little or no post-processing, concrete is a material with advantageous properties for machine frames.

3. FABRICATION OF MACHINE FRAMES BASED ON CONCRETE

During the production of machine frames made of concrete, a solid body is built from shapeless material in a primary molding process, similar to the casting of metals. It is carried out using a multiphase mixture of materials rather than molten casting materials. This results in the following processing steps:

- Metering: The aggregates, i.e. fillers and binders, are metered independently according to the particle/grain fraction or their stoichiometric ratio to achieve a high packing density and thus reproducible material properties.
- Mixing: The grain fractions of the fillers and the binder[2] are mixed to form a viscous, pourable mass.
- Casting: The viscous mass is filled into the mold. In this step, the time during which the mixture is still workable (the so-called "pot life" [11]) is essential. It can vary depending on the volume and complexity of the part to be realized.
- Compacting: To achieve a low pore content, the concrete mix is compacted. This can be done by introducing vibrations[3] on mold or via tools, by degassing e.g. low-pressure casting environment or improved wetting of binder to filler by e.g. chemicals.
- Curing: Curing of the cast object in the mold. Often combined with heat management during the setting [46] of the binder under exothermic reaction.

Due to the low processing temperatures, various materials can be used for the mold. The mold consists of one or more monolithic blocks made from wood, plastic, steel or grey-cast iron or even natural stone as well as combinations of the aforementioned. Decisive for the choice of the mold material are (according to [11]):

- planned number of castings,
- requirements on the dimensional accuracy of the blanks,
- requirements on the surface quality of the blanks.

Steel, cast iron and natural stone components are used for a high number of castings and a high quality of the blank. To a cold primary shaping process wood and plastic molds can also be applied for castings with prototype character or lower precision requirements. The low temperature process also makes it possible to create integrated structures in composite castings. In this process, certain components (e.g. bearing blocks, metal plates, cable ducts or e.g. piping systems) are cast in or on. Especially the latter saves time-consuming rework and can utilize comparably cheap parts from plastics.

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[2] Epoxy or resin (including hardener if needed) for polymer concrete and cement for hydraulic concrete.

[3] Note that some of these measures could be mutual exclusive, e.g. self-compacting by chemicals and vibrations.

3.1 Realization of precision geometric features on concrete-based machine frames

A variety of manufacturing processes are feasible to realize precision features in general and for concrete structures in specific, as summarized in Table 2. For the further discussion aerostatic guides are again used as an example with demanding requirements.

For the manufacturing of aerostatic guide surfaces in classic materials, the finishing processes of grinding and lapping are used. Those can be applied for concrete as well enabling roughness values of Ra 1.6 to 6.3 µm and Rz 6.3 to 25 µm [47]. Although grinding and lapping have been considered for mounting surfaces for rolling guide systems [48-50], the requirements for guide surfaces for aerostatic elements have not been met so far [48]. One of the main reasons is varying strength of aggregates and binders which can be a cause of cracking or chipping in addition to roughing up.

Table 2: *Options to produce functional surfaces suitable for air bearings according to manufacturing process and time of shaping.*

final shaping	**Process**			
	grinding/lapping	**molding**	**embedding**	**add-on molding**
direct	-	X	X	-
subsequently	X	X	X	X

Alternatively, precise geometries such as guide surfaces for aerostatic guides can be made by direct replication of a mold surface with sufficiently small form deviations. In mechanical engineering, this approach is not entirely new. As early as the beginning of the 19th century, there were efforts to replace components made of steel and cast iron with components made of concrete - albeit with a lower demand on the achievable precision in the order of several 100 µm for flatness [11].

There are two basic options:

- directly during the molding process or
- subsequently by add-on molding with a further compound.

With direct molding, parts can be produced with the required tolerances and with good material homogeneity. This process has the highest potential to reduce overall manufacturing costs for precision components, as the amount of time-consuming and cost-driving post-processing by grinding and lapping is eliminated or substantially reduced.

In 2000, primary shaped precision surfaces with reasonable flatness and roughness were obtained with polymer concrete. Difficulties arose due to heating and shrinkage during curing. A multitude of research work on different resins, fillers and active tempering laid the foundations for this [11, 40 and 51-54]. In 2010, it was shown that primary shaped surfaces in hydraulic bound concrete with flatness and roughness in the single-digit micrometer range have proven to be achievable with self-compacting concrete (SCC) [26].

Research has shown for both, polymer and hydraulic-bound concrete, shrinkage as the biggest challenge of molding. The curing of the concrete itself but also the dehumidification over extended periods of time causing deformations in the same order of magnitude of the required precision [26]. Shrinkage caused by the aforementioned effects is difficult to predict, especially with complex geometries and in the presence of inlaid parts. However, it can be effectively reduced by process engineering measures [55] and design measures such as reinforcing elements with adjustable preload as in patent DD 00133201 A1 [48].

In contrast, the subsequent shaping process of "add-on molding" has the advantage that it can take place after the shrinkage of the support body have decayed. The demand on the geometric precision of the subsurface where the add-on layer is applied to is low[4] as it is compensated by the added layer. Since the thickness of the applied layer during the add-on molding process is supposed to be small in relation to the overall dimensions, its relative shrinkage has only a minor influence on the residual shape deviations of the specific feature.

However, the application of additional layers is a delicate process and raises design constraints and is limited to concretes of small sized grain fractions. The resulting shape deviations of add-on molding also depends on the flow properties of the added material and the process control. Furthermore, the process introduces inhomogeneity which can cause stresses and so deformations that are difficult to control or predict.

Another way to realize precise guiding features is to embed parts with functional surfaces into a concrete base structure. Figure 3 shows examples of typical mounting inserts. Embedding of parts with high demands on position and shape accuracy requires complex casting tools/molds with comparable precision or post-processing of the embedded elements. However, embedding allows to use parts with specific material properties where they are needed. In many cases, embedding components in concrete of low accuracy requirements is used as a cost-effective solution to hold precision parts in position. Especially for large machine frame structures the embedding of (usually pre-machined) elements with precision surfaces is an affordable option.

In addition to embedding, the reverse filling of e.g. steel or cast iron frame structures with concrete is also common. Mainly with the aim of achieving improved damping, numerous examples of this approach exist [24]. Shrinkage of concrete is a major challenge again since it causes displacement and/or deformation of the embedded parts resulting into cracks due to stress concentration in or even disconnection of concrete with respect to the inlayed or filled parts. It should be noted that shrinkage leads to tensile stresses that are unfavorable for concrete.

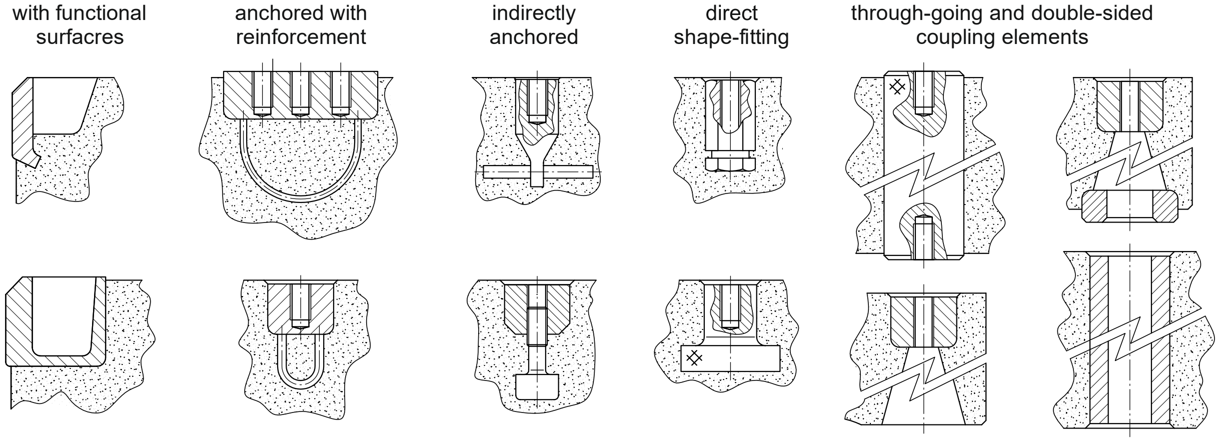

Figure 3: *Examples of typical inlets (derived and adapted from [38][5])*

Regarding the combination of inlays and concrete, however, a cast around is technologically interesting. Since the encapsulated object is “clamped” by the shrinking concrete, the concrete cannot separate from the covered parts and by proper design a compression preload can be achieved in many cases. This considerably reduces the risk of the occurrence of cracks or cavities.

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[4] As a rule of thumb form deviations and/or roughness of up to 1/10th of the add-on layer can be accepted.

[5] [38] is referring to [56] which was not accessible to the authors.

3.2 Long term stability of concrete compared to precision engineering requirements

Like natural stone or cast iron, concrete features are affected by anisotropic material behavior, i.e. a higher compressive strength than tensile strength. Therefore, like natural stone, concrete machine frame designs are optimized to reduce tensile and bending stresses. A distinct difference of concrete compared to cast iron and natural stone is a stronger tendency to creep. Moreover, the creeping properties of polymer concrete and hydraulic bound concrete are different as a result of different binders.

Polymer concrete exhibits a temperature dependent nonlinear decaying creep under mechanical load [32, 57]. The binder used in polymer concrete is the reason of the significant creep under load, which increases with temperatures above room temperature. Therefore the stability of machine frame parts made from polymer concrete is in general dependent on the level of mechanical load applied, the type of binder and ratio between binder and aggregates used [32, 33]. Thereby:

- higher relative amount of binder results in higher creep [33],
- polymer concrete with PMMA binders tend to creep more under load than those using epoxy binders [32],
- grain fractions with a higher proportion of larger aggregates show a lower degree of creep [33],
- the creep rate increases with the temperature; exceeding the glass transition temperature of the binder must be prevented.

Components made of polymer concrete can therefore not be loaded to their strength limit, so they must be significantly over dimensioned. As a rule of thumb, peak loads of polymer concrete should not exploit more than 50% of nominal strength and a 50% decrease of strength is to be expected if the part is heated up from 20ºC to 60ºC.

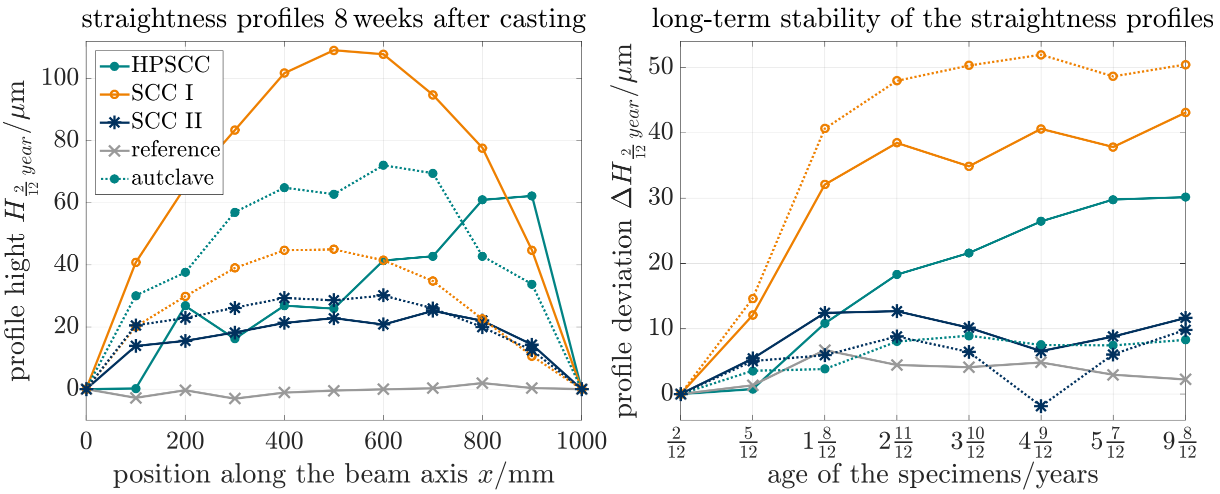
The latter aspect is of special importance, since polymer concrete has a low thermal conductivity, which easily leads to the formation of local hotspots in the proximity of heat sources (e.g. drive motors). These consequentially will locally decrease strength and cause hardly predictable deformation due to creep even with static loads.

Compared to polymer concrete, hydraulic bound concrete is less sensitive to creep under mechanical load and due to the non-organic binder less sensitive to thermal changes [3]. Creep of hydraulic bound concrete is mostly driven by transformation of the binder (short term) and dehumidification (long term). Short term in this context refers to 30 days up to 8 weeks after molding the concrete. Long term investigations [55, 58] show large potential to reduce creep by adapted concrete mixtures and post treatment (see Table 3). By optimized concrete recipes creep levels equivalent to that of natural stone can be achieved [3].

Table 3: *Long-term stability over 10 years and stabilization time for the straightness deviation of specimens made of different concrete mixtures compared with natural stone*

Specimen dimensions 1030 mm × 120 mm × 100 mm	**HPSCC**	**SCC I**	**SCC II**	**n. stone**
straightness deviation without post-treatment	±14,5 µm	±2,5 µm	±3,0 µm	±1,8 µm
straightness deviation after treatment in an autoclave	±2,5 µm	±3,0 µm	±6,5 µm	---
stabilization time without post-treatment	≥5 years	≈3 years	≈8 weeks	---
stabilization time after treatment in an autoclave	≈12 weeks	≈3 years	≈8 weeks	---

The effect of creep on precision features was investigated by observing straightness over 10 years [55]. These investigations show air bearing suitable, micrometer-level shape stability in lab environment after a first stabilization period of 8 weeks, comparable to natural stone elements (see Figure 3).


straightness profiles 8 weeks after casting

long-term stability of the straightness profiles

Figure 3: *Straightness measurements of sample profiles and their deformation over length and over time. Note that the error budget of the individual measurements of <±0,5 µm is not shown (for details see [55]).*

4. IMPLICATIONS OF CONCRETE PROPERTIES FOR MACHINE FRAME DESIGN

The studies show that the on-site availability of concrete significantly shortens the manufacturing time of structural components compared to natural stone to be sourced from distant places, even considering the necessary setting time. Although it is difficult to quantify or define a clear threshold, the costs of conventional manufacturing technologies are increasing with the complexity of a part. The advantages of concrete are increasing proportional to the size and complexity of the part and ready-to-use molded concrete structures become an interesting alternative.

As shown in Table 1 and Table 3 hydraulic-bound concrete types with strength and stability properties comparable to natural stone are available and could be casted to complex forms with comparatively simple means. Furthermore, concrete enables to create structures with significant thermal inertia, comparatively low thermal conductivity and a coefficient of thermal expansion close to steel.

Based on the freedom of design offered by the primary shaping, connectors, ducts and hoses for fluids, cable and other elements can be easily integrated. Shrinkage during curing is fundamentally a problem. However, measures are known to deal with this problem and to exploit the full advantages of the primary shaping process. Since especially hydraulic-bound concrete is a well-known material in civil engineering it is more about adapting than inventing rules and procedures for precision engineering applications.

5. CONCLUSION AND OUTLOOK

In this contribution progress made in research of concrete for mechanical engineering applications has been shown and references for further investigation for specific aspects have been summarized. The feasibility of performing precision features in a casting process has been demonstrated on a laboratory scale. The long-term stability of structural elements based on hydraulically bound concrete has been demonstrated in various investigations. Post-processing options such as grinding or the application of additional layers have been discussed. Due to its long-term stability, the potential of integrating components and the possibility of reworking, concrete is a promising alternative to natural stone and cast iron. Delivery times can be significantly reduced.

In addition, there are further interesting aspects of concrete in the field of application of precision engineering. Among others, the combination of polymer concrete and hydraulic bound concrete and its influence on dehumidification shall be mentioned. Pouring polymer concrete onto a hydraulic bound concrete base is an interesting concept, minimizing the risk of shrinkage and allowing for reworking. The chemical resistance and low absolute creep rates of a thin polymer concrete layer can be combined with high stability of the concrete frame. The combination of simple basic molds in combination with precision molding has potential for application-oriented and cost-effective solutions. Another interesting research field is the reinforcement hydraulic bound concrete systems by coatings to enable thin-walled structures or prevent surfaces cracks [61, 62].

REFERENCES

[1] Reitz, E.: *Maschinenbetten aus Granit und Gabbro*, Industrie-Diamanten-Rundschau, IDR 35, Nürnberg, 2001

[2] Weck, M., Brecher, Ch.: *Werkzeugmaschinen, Konstruktion und Berechnung*, 8. Auflage, Springer-Verlag, 2006

[3] Relea, E., Pfyffer, B., Weiss, L., Wegener, K.: *Experimental comparative investigation on creep behavior of mineral cast, ultra-high-performance concrete, and natural stone for precision machinery structures.* The International Journal of Advanced Manufacturing Technology. 2021 Dec; 117(7-8):2073-81.

[4] Poklemba, R., Zajac J, Dupláková, D., Petruška, O.: *Design of bed machine for machine tool based on polymer concrete mixtures.* TEM J. 2020 Feb 1;9(1):25-9.

[5] Kemmerle, D.: *Einsatzoptimierte Konstruktion eröffnet Mineralguss weitere Möglichkeit*, Werkstatt und Betrieb 123, 1990

[6] Gerloff, H.: *Beitrag zum Einsatz von Reaktionsharzen in Werkzeugmaschinen*, Diss. Braunschweig 1988

[7] Etmanski, B.: *Zum Eigenschaftsprofil hochgefüllter Reaktionsharzverbundwerkstoffe*, Diss. Universität Kassel, 1992

[8] Stauss, O.: *Mineralguss dämpft Maschinenschwingungen*, in: Industrieanzeiger 16/98 (1998), S. 126-127.

[9] Sahm, D.: *Reaktionsharzbeton für Gestellbauteile spanender Werkzeugmaschinen*, Diss., Aachen 1987

[10] Nachname, Vn.?: *Polymerbeton als eine Alternative für Werkzeugmaschinengestelle*, in: Maschinenmarkt 42 (1983), S.959

[11] Jackisch, U.: *Mineralguss für den Maschinenbau*, Verlag Moderne Industrie, Kassel 2002

[12] Nicklau, R.: *Werkzeugmaschinengestelle aus Methacrylatharzbeton*, Forschungsbericht VDI Reihe 2 Nr. 94, Düsseldorf VDI-Verlag 1985

[13] Kosmol, J., Lis, K., Całka, P.: *Comparative Tests of Static Properties of Steel and Polymer concrete Machine Tool Body Elements*. In: Mężyk, A., Kciuk, S., Szewczyk, R., Duda, S. (eds) Modelling in Engineering 2020: Applied Mechanics. SMWM 2020. Advances in Intelligent Systems and Computing, vol 1336. Springer, Cham. https://doi.org/10.1007/978-3-030-68455-6_12

[14] Niaki, M., Ahangari, M.: *Polymer concretes: Advanced Construction Materials*. CRC Press; 2022 Dec 30.

[15] Relea, E., Weiss, L., Wegener, K.: *Dimensional Stability of Mineral Cast for Precision Machinery.* InSmart, Sustainable Manufacturing in an Ever-Changing World: Proceedings of International Conference on Competitive Manufacturing (COMA’22) 2023 Mar 4 (pp. 685-699). Cham: Springer International Publishing.

[16] Troncossi, M., Canella, G., Vincenzi, N.: *Identification of polymer concrete damping properties.* Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. 2022 Nov;236(21):10657-66.

[17] Dal, H., Kurt, A., Yıldız, S.: *Vibration characteristics of mineral composite beams by experimental modal test method.* Materials Testing. 2022 Sep 1;64(9):1365-71.

[18] Long, Y., Zhang, Y., Hu, X., Zhang, Q., Zhang, J.: *Optimization of mechanical and thermal expansion properties of resin mineral composites for ultra-precision machine tools.* Journal of Reinforced Plastics and Composites. 2022;0(0). doi:10.1177/07316844221141384

[19] Deredas, K., Kępczak, N., Urbaniak, M.: *Influence of doping with styrene-butadiene rubber on dynamic and mechanical properties of polymer concrete.* Composite Structures. 2021 Jul 15;268:113998.

[20] Öztürk, H., Kahraman, Y.: *Effects of glass fiber reinforcement to tensile strength in epoxy matrix granular composite materials*. Sakarya University Journal of Science. 2019 Oct 1;23(5):736-43.

[21] Hahm, C., Theska, R., Fehringer, A., Kästner, A.: *Qualification of the endurance strength enhancement of silane coated concrete parts.* Measurement Science and Technology. 2018 Aug 31;29(10):104003.

[22] Kepczak, N., Pawlowski, W.: *Mechanical properties of the mineral cast material at the macro and micro level.* Mechanics and Mechanical Engineering. 2016; 20(3):249-54.

[23] Kępczak, N., Pawłowski, W., Błażejewski, W.: *The study of the mechaical properties of the mineral cast material*. Archives of Mechanical Technology and Automation. 2014; 34(2).

[24] Kępczak, N., Pawłowski, W.: *Cast iron and mineral cast applied for machine tool bed-dynamic behavior analysis.* Archives of Metallurgy and Materials. 2015;60(2A):1023-9.

[25] Selvakumar, A., Ganesan, K., Mohanram, P.: *Dynamic analysis on fabricated mineral cast lathe bed*. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 2013 Feb; 227(2):261-6.

[26] Berg, M., Bernau, R., Erbe, T., Bode, K., Theska, R.: *Primary shaping of smooth and level guideway planes for high precision applications.* In Proceedings of the 10th International Conference of the European Society for Precision Engineering and Nanotechnology, Delft 2010 May (Vol. 1, pp. 279-282).

[27] Klaeger, S., Bär, J.: *Werkstoffuntersuchungen zur Erarbeitung eines Mineral-guss-Werkstoffkataloges für die Konstruktion und Fertigung von Maschinenbauerzeugnissen; Schlussbericht zum MO¬DYMA Teilprojekt 1*; Universität Magdeburg, 2005

[28] Dou, K.: *Thermisch bedingtes Deformationsverhalten von Mineralguss- Metall-Verbundkonstruktionen in Werkzeugmaschinen*, Sinzheim, Pro. Universitate Verlag, 1995

[29] Barth, T.: *Modell zur Beschreibung mechanischer Kurzzeitkennwerte des Werkstoffes Reaktionsharzbeton*, Diss. Darmstadt 1993

[30] Dey, H.: *Das Verformungs- und Bruchverhalten von Reaktionsharzbeton und die Auswirkungen auf Maschinenbauteile*, Diss, Darmstadt 1991

[31] Schulz, H.: *Qualitätssicherung von Polymerbeton*, in: QZ Qualität und Zuverlaessigkeit, 29(5), TW/TH Darmstadt, 1984, S. 140-147.

[32] Krausse, J.: *Reaktionsharzbeton als Werkstoff für hochbeanspruchte Maschinenteile*, Diss., Darmstadt 1987

[33] Neumann, M.: *Werkstoffgerechte Gestaltung und wirtschaftliche Fertigung dauerhaltbarer Maschinenbauteile aus Mineralguss*, Diss. Aachen 1985

[34] Rohmann, J., Koblischek, P.: *MOTEMA-Acrylbeton, Konstruktionshinweise für Werkzeugmaschinengestelle*, Frankfurt am Main, 1982

[35] Fritz Studer AG, Broschüre - The Art of Grinding, V3 · 06/2018, https://www.studer.com/de/rundschleifmaschinen/rundschleifen/product/s141/#image-gallery-1, last accessed 09. July 2023

[36] Budak, E., Matsubara, A., Donmez, A., Munoa, J.: *Mechanical interfaces in machine tools.* CIRP Annals. 2022 Jun 16. https://doi.org/10.1016/j.cirp.2022.05.005

[37] Erbe, T.: *Untersuchung der Eigenschaften von Reaktionsharzbeton und Vergleich mit etablierten Gestellwerkstoffen*. Diplomarbeit. Ilmenau: Technische Universität Ilmenau, 2007.

[38] Erbe, T., Król, J., Theska, R.: *Mineral Casting as Material for Machine Base-frames of Precision Machines*. Twenty-third Annual Meeting of the American Society for Precision Engineering and Twelfth ICPE, October 2008, Portland, Oregon (2008).

[39] Bargel, H.-J., Schulze, G.: *Werkstoffkunde*, München. Springerverlag, 2000

[40] Relea, E., Weiss, L., Wegener, K.: *Experimental Study on the Geometrical and Dimensional Stability of Natural Stone Sorts for Precision Machinery*. Procedia CIRP. 80. 89-94. 10.1016/j.procir.2019.01.107.

[41] Andersson, E.: *Thermal properties in different rock materials based on hot disk and mineral mode – a comparison between petrographic analysis and laboratory measurements.* Masterthesis. University of Gothenburg. 2016.

[42] Hahm, C., Theska, R., Flohr, A., Dimmig-Osburg, A., Hartmann, O.: *Concrete – future material for high precision machines.* In 58th Ilmenau Scientific Coll. 2014 Sep.

[43] Baumeister, E.: *Hohlkugelkomposit- Charakterisierung thermischer und mechanischer Eigenschaften eines neuen Leichtbauwerkstoffes*, Diss. 2004

[44] Chen, J., Zeng, X., Umar, H. A., Xie, Y., & Long, G.: *Study of the Vibration Reduction Performance of Rubberized Self-Compacting Concrete Filling Layer in Prefabricated Slab Track*. Journal of Materials in Civil Engineering, 35(6), 2023.

[45] Bala, A., Gupta, S.: *Thermal resistivity, sound absorption and vibration damping of concrete composite doped with waste tire Rubber: A review.* Construction and Building Materials, 299, 2021.

[46] Czernin, W.: *Betonhärtung bei höheren Temperaturen*. In: Zement und Beton Nr. 2 (1955), S. 513.

[47] Krause, W. (editor) et al: *Konstruktionselemente der Feinmechanik*. 4., aktualisierte Auflage. München: Carl Hanser Verlag GmbH & Co. KG, 2018.

[48] Nietzelt, M.: *Führungsflächen an Werkzeugmaschinengestellen und Verfahren zu ihrer Herstellung.* VEB Werkzeugmaschinenkombinat. Patentschrift: DD 00133201 A1, 1978.

[49] Alexander, M.: *Towards standard tests for abrasion resistance of concrete report on a limited number of tests studied, with a critical evaluation*. In: Materials and Structures Nr. 4 (1985), S. 297–307.

[50] DIN EN 13748–2: *Terrazzoplatten Teil 2: Terrazzoplatten für die Verwendung im Außenbereich*; 2005.

[51] Maschinen Markt: *Epucret weiht Schleifzentrum ein.* Vogel Communications Group GmbH & Co. KG. 2010. url: https://www.maschinenmarkt. vogel.de/epucret-weiht-schleifzentrum-ein-a-269237/ (zuletzt abgerufen am 11. 09. 2022).

[52] Rogers, A.: „A process for constructing machine tools“. Cemtronics Inc. Patentschrift: EP 0253930 A1, 1986.

[53] Vaerst, K.: *Maschinensockel mit Führungsflächen und Verfahren zu dessen Herstellung*. Siemens AG. Patentschrift: DE 10251228 C1, 2003.

[54] Gropp, H.: *Verfahren zur Herstellung von Teilen aus einem kalt ausgehärteten Mineralguß*. Innovative Fertigungstechnologie GmbH. Offenlegungsschrift: DE 19714736 A 1, 1998.

[55] Hahm, C., Theska, R., John, K.; Flohr, A., Osburg, A.: *Concrete based parts for high precision applications*. In: Proceedings of the 13th International Conference of the European Society for Precision Engineering and Nanotechnology, (2013), S. 171-174

[56] Fritz Studer AG: *GRANITAN-Engineering: Mineralguss GRANITAN*. booklet V. 3.9

[57] EPUCRET Mineralgusstechnik GmbH & Co. KG: *Hydrophobe Wirkung von EPUCRET-Mineralguss*, Kundeninformation, 2007

[58] Flohr, A., Dimmig-Osburg A., Hahm, C., Theska, R.: *Funktionsfertig urgeformte Betonbauteile für den Präzisionsmaschinenbau*. In: BWI -Beton Werk International Nr. 6 (2014), S. 45–52.

[59] Ramana, M., Thyla, P., Subramanian, E, Chinnuraj, S.: *Thermal Investigations on a CNC Lathe Fitted with a Dynamically Enhanced Steel-Reinforced Epoxy Natural stone Bed.* Strojniški vestnik-Journal of Mechanical Engineering. 2023 Mar 29;69(3-4):169-84.

[60] DIN 1045–2: *Tragwerke aus Beton, Stahlbeton und Spannbeton – Teil 2: Beton*. 2022.

[61] Hahm, C., Theska, R., Raab, D., Mitterhuber, M., Kästner, A.: *Strength enhancement of precision concrete parts by sol-gel surface coating*. In: Proceedings of the 17th International Conference of the European Society for Precision Engineering and Nanotechnology / European Society for Precision Engineering and Nanotechnology International Conference 17. 2017 Hannover. - Bedford: euspen, 2017

[62] Hahm, C., Theska, R., Raab, D., Fehringer, A., Kästner, A.: *Experimental qualification of the strength enhancement of coated concrete parts*; In: Proceedings of the 18th International Conference of the European Society for Precision Engineering and Nanotechnology / European Society for Precision Engineering and Nanotechnology International Conference 18. - Bedford, UK: euspen, 2018

CONTACTS

Dipl.-Ing. Christoph Hahm	email:	christoph.hahm@tu-ilmenau.de
Dr.-Ing. Torsten Erbe	email:	torsten.erbe@asml.com
	ORCID:	https://orcid.org/0000-0002-3032-9283