Non-conventional Materials for Machine Tool Structures*

Mustafizur RAHAMAN**, Md. Abul MANSUR***
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Non-conventional materials are the emerging demand for machine tool structures, while smooth operations have been hindered due to vibration and thermal deformation of machine tool structures, especially in precision machining. This paper attempts to review and summarize the key developments in the area of non-conventional materials for machine tool structures over the last two decades. Many beneficial properties of the machine tool structural materials are compared with the conventional cast iron. To support the ever-rising working speeds made possible by the development of tools and machining processes, the increasing requirements concerning the surface finish of the machined workpieces and the fabrication cost of the machine tool structures exerted the impetus to find alternatives to cast iron. Based on the results of previous studies, composite materials may be the paragon.

Key Words: Machine Tool, Structural Materials, Composites

1. Introduction

Gray cast iron, naturally or artificially aged has long been the material of choice and been considered as a conventional material for machine tools structure. Cast iron was inexpensive and also exhibited good material damping characteristics to minimize the influence of dynamic loads and transients. The high initial cost of fabricating patterns and molds, and the generally poor environment of operating foundries, gave the impetus to find alternatives to cast iron[1].

High static stiffness against bending and torsion, good dynamic characteristics (as reflected by high natural frequency and high damping ratio), ease in production, good long term dimensional stability, reasonably low coefficient of expansion, low cost and low material requirements are the basic properties of machine tool structures that engineers look for designing and fabricating[23-46]. However, from users' point of view, machine tool vibration is an important factor, because it adversely affects the quality of a machined surface. When the machine tool is operated without any vibration or chatter, its damping property plays no important role in machining. However, the machine tool structure has several resonant frequencies because of its continuous structural form. If the damping is too small to dissipate the vibration energy of the machine tool, resonant vibration occurs when the frequency of the machining operation approaches one of the natural frequencies of the machine tool structure. To improve both the static and dynamic performances the machine tool structure should have high static stiffness and damping[75-88].

Using either higher modulus material or more material in the structure, the static stiffness of a machine tool may be increased. But, it is difficult to increase the dynamic stiffness of a machine tool with these methods because an increase in the static stiffness can not increase its damping property. The best way to increase the damping capacity is to use a

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composite material, consists of one material with high stiffness but low damping and another material with low stiffness and high damping. The resulting composite material can have both moderate modulus and damping\textsuperscript{(9,29)}.

The need for higher material damping and ultra precision machining situation combined with long term dimensional and geometrical stability has led to the development of alternative materials for the replacement of traditional cast iron. They include granite, ceramics, polymer concrete and cementitious composites. Although various degrees of success have been achieved with each material, some problems still exist.

In the early stage, mild steel weldments, granite and ceramic\textsuperscript{18} received a lot of research attention as non-conventional material for machine tools structure. Among them ceramic has been found to be most promising replacement material due to its high specific rigidity and low thermal coefficient of expansion\textsuperscript{10–12}. Because of low damping capacity and brittle properties ceramic could not support to avow its superiority. Polymer concrete may be the answer. It presents fewer constraints to the designer and takes less time and energy when compared to cast iron\textsuperscript{13–18}.

A series of investigation had been carried out at the National University of Singapore to explore the feasibility of replacing cast iron with other materials, particularly with ferrocement, a relatively new development in material technology. In one of the studies\textsuperscript{19,20} the conventional bed of a center lathe was duplicated using ferrocement and, static and dynamic test, were carried out to assess its performance in comparison with the parent cast iron bed. Test results indicate that replacement of traditional cast iron structural components of a machine tool by a relatively new material, ferrocement, is not only feasible, such a replacement also yields highly improved dynamic performance. However, experiences with ferrocement construction have shown that fabrication of structural components is rather labor intensive because of the difficulty in cutting, bending and tying the fine wire mesh in the form of cages\textsuperscript{19–22}.

Fiber reinforced concrete is increasingly attracting the attention of engineers worldwide because of such favorable performance characteristics as high strength to-weight ratio, resistance to corrosion and magnetic neutrality. It is ordinary concrete containing discrete fibers of short length and small diameter. The fibers are usually added to the concrete during mixing of its ingredients and the resulting fiber concrete is directly poured into the mould, thus considerably simplifying the construction process\textsuperscript{23,24}.

Investigation\textsuperscript{25} carried out indicate that a fiber reinforced concrete column with 3% volume fraction of fibers possesses adequate dimensional stability, strength and stiffness to justify its use as a suitable replacement material. Fiber reinforced column also exhibited dynamic properties quite comparable to those of ferrocement, a material that showed marked improvement over cast iron in an earlier investigation. Since use of fiber reinforced concrete leads to a much simpler fabrication process; it provides more attractive replacement material than ferrocement\textsuperscript{25,26}.

2. A Comparative Study on Recent Progress in Machine Tool Structural Materials

The performance of a structure is directly associated with the mechanical and physical properties of the material used to build it. The structure is a machine's fundamental component. The following factors govern material choice: the material must resist deformation and fracture, hardness must be balanced against elasticity; the frame must withstand impact; yet yield under load without cracking or permanently deforming, the frame material must eliminate or block vibration transmission to reduce oscillations that degrade accuracy and tool life, it must withstand the hostile shop-floor environment, including the newer coolants and lubricants, the material must not build up too much heat, must retain its shape during its lifetime, and must be strong enough to distribute forces throughout the machine\textsuperscript{27}.

Almost all machine tool frames were traditionally made of cast iron because features difficult to obtain any other way can be cast in. Cast iron has a good stiffness-to-weight ratio and good damping qualities. Modifying wall thickness and putting the metal where it is needed, is fairly easy and it is a fairly cheap material. On the other hand, cast iron requires a pattern for each casting, it demonstrates problems with bolted joints, and there is a need to anneal casting, which is difficult and costly with larger sections. Several attempts to replace cast iron for machine tool structures have been made in the past. The alternative materials investigated for the replacement include: mild steel weldments, granite, polymer concrete, ferrocement and fiber reinforced cement composites. Although various degrees of success have been achieved with each material, some problems still exist.

A great deal of research and development is still in progress on non-conventional materials for machine tools structure. The research covers both theoretical and experimental studies. As space does not allow for a full discussion of current activities,
only a brief review of some of the current work is given as follows.

2.1 Mild steel weldments

Since 1950's mild steel weldments have been used more and more as a machine tool structural material. Machine builders fabricate steel frames from welded steel sections when casting is impractical. Because steel has a higher modulus, it is usually ribbed to provide stiffness. The number of welds is a design tradeoff. With welding, it is easy to make large sections and add features even after the initial design is complete, but the heat can introduce distortion. Welds also help block vibration transmission through the steel frame. Builders sometimes increase damping by circulating coolant through the welded structure or adding lead or sand to frame cavities.

These structures possess high strength and stiffness. By using mild steel weldments less material would be required to provide necessary strength and stiffness of the structure and, if necessary, thin wall section may be used. This results in reducing the weight of a machine tool. However, they have several disadvantages. The material damping is low and mild steel weldments have a tendency to ring. The fabrication cost is high and the production cycle time is long, as it needs special finishing, stress relieving and corrosion treatment. It is also difficult to carry out inspection on internal weld.

2.2 Granite

Granite can be used for surface tables and measuring machine structures. Better internal damping, good wear resistance property and reasonable dimensional stability are the major requirements for a material to replace cast iron and granite possesses all of those qualities. However, it has a number of limitations such as the difficulty to be machined to the required size and shape, the increasing scarcity and price, and low conductivity, which may lead to heat concentration and eventual cracking of the material. In addition, it has another drawback as it absorbs coolant resulting in dimensional changes.

2.3 Ceramics

The machine tool researcher's, introduced experimental machine tools with ceramic frames. Ceramics offer strength, stiffness, dimensional stability, corrosion resistance, and excellent surface finish, but they are brittle and expensive. Their lack of conductivity can be an advantage.

Furukawa et al. showed Alumina ceramics might be one of the proper materials, which can answer to the ultra-precise machining requirements in the future. According to Furukawa, ceramic's specific rigidity is about 5 times larger than that of cast iron. It means that the guide-bar supported at the both ends may deform about one fifth smaller than that of cast iron. In a similar way, the difference in the coefficient of thermal expansion can suppress the thermal distortion up to 60%.

The merits to utilize Alumina ceramics for an ultra-precision machine tool are considered as follows: high specific rigidity brings lower deformation; low thermal coefficient of expansion decreases the structural thermal distortion; no plastic deformation at room temperature offers high stability of shape; chemically stable and no possibility of rusting; hard and high wear resistance and ease to obtain completely flat surface; relatively easy to obtain any shape.

On the contrary, Alumina ceramics poses some demerits as follows: brittle and weak in shock; low damping capacity; porous structure and weak for concentrated load.

2.4 Polymer concrete

Polymer concrete, a new type of composite is finding its way into a variety of applications from machine tool and precision instrument bases to industrial floor drain channels, pump bases and gear cases. Polymer concretes are the materials, which are made by replacing a part or all of the cement hydrate binder of conventional mortar or concrete with polymers, and by strengthening the cement hydrate binder with polymers.

Polymer concrete (PC) is not a concrete, in the usual sense of the word. The most common form of polymer concrete consists of a base resin, a mineral or synthetic aggregate filler, a catalyst and an accelerator. The properties of polymer concrete are dependent on the matrix material and the kind and size of the filler.

The mixture is poured into a mold, usually vibrated to minimize air bubbles and to compact the mixture and the finished part is de-molded in 15 to 120 min, depending on its mass. The cast components can be easily machined, although machining is unnecessary for most parts. Some of the properties of polymer concrete are compared with those of steel and cast iron in Table 1. From the table it may be observed that, polymer concrete possess low Young's modulus. But, its low thermal conduction is desirable. The most attractive property of polymer concrete is its damping property. Figure 1 obtained from the work of Peter Menz shows vibration at a laser cutting machine with frames made from polymer concrete when vibration stimulated by to and fro movement of the cutting head. The periodic stimulation and also the short decay-time of the natural vibration can be noted in Fig. 1.

The term polymer concrete is sometimes used to describe two other completely different types of...
Table 1 Properties of different materials

<table>
<thead>
<tr>
<th></th>
<th>Dimension</th>
<th>Steel ST 37</th>
<th>Cast Iron</th>
<th>Concrete with Epoxy resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Kg/dm³</td>
<td>7.85</td>
<td>7.15</td>
<td>2.1-2.4</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>KN/mm²</td>
<td>210</td>
<td>88-113</td>
<td>30-50</td>
</tr>
<tr>
<td>Strength of extension</td>
<td>N/mm²</td>
<td>350-470</td>
<td>200-300</td>
<td>10-20</td>
</tr>
<tr>
<td>Strength of compression</td>
<td>N/mm²</td>
<td>720</td>
<td>100-800</td>
<td></td>
</tr>
<tr>
<td>Thermal Coefficient of expansion</td>
<td>10⁻⁷ K</td>
<td>12</td>
<td>10</td>
<td>12-20</td>
</tr>
<tr>
<td>Thermal Conductance</td>
<td>W/mK</td>
<td>50</td>
<td>50</td>
<td>1.3-2.6</td>
</tr>
</tbody>
</table>

Fig. 1 Vibration of a laser-cutting machine with frames made from polymer concrete

Fig. 2 Photograph of the resin concrete bed

properties of the resin concrete bed compared with those of cast iron bed, it was found that the damping ratio of the resin concrete bed was 9 times greater than that of the cast iron bed. Since the specific modulus of the resin concrete is a little smaller than that of the cast iron, the resin concrete bed should be designed a little heavier to give the same stiffness.

The epoxy resin concrete has a coefficient of linear expansion approximately equal to that of cast iron, and a thermal conductivity much smaller than that of cast iron. Epoxy concrete can take both compressive and tensile forces, therefore, steel reinforcement is unnecessary in most cases. It has properties much better than traditional concrete. Experiences have shown that the internal damping factor of resin concrete is 10 times that of cast iron and 3 times that of granite.

Unfortunately it is quite expensive, as the price of a synthetic resin binding agent, which is specially suitable and critical for the production of machine component, is significantly greater than that of traditional mineral cement. Therefore it may not be economically substitute for cast iron material at present.

2.4.2 Polymer-impregnated concrete (PIC) Polymer-impregnated concrete obtained with hardened ordinary concrete, which are permeated with monomers of sufficient viscosity. The polymerization is obtained by chemical means, by heat or radiation.

In polymer-impregnated concrete, the system of pores in hardened cement is filled by liquid monomers. The effects are a multiple-decrease in porosity; formation of reinforcing system in the porous hardened matrix; increase in matrix aggregate and matrix reinforcement bond; and modification of the internal stress state by decreasing the stress concentration.

To improve damping in CNC machine table by replacing the conventional steel damping carriage, polymer-impregnated cellular concrete was designed, fabricated (shown in Fig. 3) and incorporated into the linear guide-ways system. Figure 4 shows the machine table structure.

To get polymer impregnated cellular concrete, the specimen was treated to full polymerization
process by first drying in an oven to 110°C to constant weight. It was cooled in a desiccator to prevent moisture absorption, vacuumed it in a vacuum chamber at 750 mmHg for 30 minutes to remove entrapped air. Next, methyl methacrylate (MMA) was injected with 1% interior into the vacuum chamber. The vacuum was released slowly after the specimen was soaked in monomer for 24 hours. To polymerize the specimen, the concrete specimen was removed from the monomer and wrapped in aluminum foil to reduce evaporation loss. It was then placed in an oven at 110°C for 4 hours to polymerize the monomer, after which the concrete specimen was immersed in water bath maintained at 80°C for 6 hours. Thus, the polymerization process was completed.

The newly designed polymer impregnated cellular concrete damper not only found to have an improved damping capacity over the steel damper linear guide system, it also compensated the design imperfection in the linear guidance system, i.e., provided high damping at lower frequency range. Table 2 shows a comparison of its damping performance with steel damper.

2.5 Hollow composites sphere

Hollow sphere composite(18), a new type of material has been developed at the University of Magdeburg, which reduced the weight of a milling machine table by one quarter of the original steel table shown in Fig. 5. It consists of hollow spheres as filler and epoxy resin as the matrix material. The hollow spheres consist of a mixture of metal oxides (SiO₂, Fe₂O₃, Al₂O₃), Corundum (Al₂O₃) or plastic. The spheres size ranges from as small as 10 μm to 2 mm. Properties of hollow sphere composite as compared to steel and polymer concrete are shown in Table 3.

2.6 Cementitious composite materials

Cementitious composites are the composites with cement as binders. Binders can include many kinds of adhesives, which provide a good bond to other constituents. Their role is to bind together fine and coarse aggregate grains and even fibers. Among the broad palate of cementitious composites ferrocement and fiber reinforced cement composites have made striking advances in recent years as a machine tool structural material(19).

2.6.1 Ferrocement

Ferrocement is a kind of

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Table 2  Modal analysis on Concrete and steel specimen

<table>
<thead>
<tr>
<th>Mode</th>
<th>Modal 1</th>
<th>Modal 2</th>
<th>Modal 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fₘ₀</td>
<td>D. R. (%)</td>
<td>Fₘ₀</td>
<td>D. R. (%)</td>
</tr>
<tr>
<td>PCC</td>
<td>1190</td>
<td>0.592</td>
<td>1880</td>
</tr>
<tr>
<td>Steel</td>
<td>1880</td>
<td>0.626</td>
<td>2040</td>
</tr>
</tbody>
</table>

Note: Fₘₐₚ Frequency, D. R. - Damping Ratio

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Table 3  Properties of hollow spheres composite

<table>
<thead>
<tr>
<th>Property</th>
<th>Steel</th>
<th>Hollow spheres composite</th>
<th>Polymer Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, Kg/dm³</td>
<td>7.85</td>
<td>1.1</td>
<td>2.1-2.4</td>
</tr>
<tr>
<td>Young's modulus, KN/mm²</td>
<td>210</td>
<td>5.1</td>
<td>30-50</td>
</tr>
<tr>
<td>Strength of extension, N/mm²</td>
<td>350-470</td>
<td>16-20</td>
<td></td>
</tr>
<tr>
<td>Strength of compression, N/mm²</td>
<td>400</td>
<td>25</td>
<td>25-35</td>
</tr>
<tr>
<td>Thermal Coefficient of expansion, 10⁻⁶/K</td>
<td>12</td>
<td>17</td>
<td>12-20</td>
</tr>
<tr>
<td>Thermal Conduction, W/mK</td>
<td>50</td>
<td>&lt;1</td>
<td>1.3-2.0</td>
</tr>
</tbody>
</table>

The table made with Hollow Sphere composite (16 kg)

The original table made with Steel (64 kg)
composite material made of cement mortar and layers
of wire mesh or similar small diameter steel mesh
closely bound together to create a stiff structural
form. Ferrocement differs from the normal reinforced
concrete in that it uses wire mesh, rather than heavy
rods or bars and it uses sands, rather than a mixer of
sand and stone in graded sizes, as the aggregate in its
concrete mix.

Ferrocement has relatively better mechanical
properties and durability than ordinary reinforced
concrete. Within certain loading limits, it behaves as
a homogeneous elastic material and these limits are
wider than the ordinary reinforced concrete.

At least two major studies had been conducted at
the National University of Singapore on ferrocement
as an alternative material to cast iron in a machine
tool structure\textsuperscript{19}-\textsuperscript{23}. A bed and the supporting legs,
both at the head and tail ends of the bed were designed
and fabricated as shown in Figs. 6 and 7 respectively,
with ferrocement.

The fine wire mesh used in the fabrication of
reinforcement cages was of welded type with 12.7 mm
square grid and 12 mm wire diameter. The skeletal
steel comprised of individual bars, 10 mm ($f_y = 460$ N/
mm$^2$) and 6 mm ($f_y = 371$ N/mm$^2$) in diameter. The
cement, sand and water ratio was 1:2:0.45.

Remarkable improvement was observed on static
and dynamic properties of ferrocement bed compared
to parent cast iron bed. Up to a load 15 kN no cracks
were observed on both the cast iron and ferrocement
beds. The complete behavior up to collapse of the
ferrocement bed was investigated under a mid span
point load. The maximum deflection for the cast iron
bed was 0.50 mm, while that for the ferrocement bed
was 0.49 mm as shown in Fig. 8. Figures 9 and 10
show, respectively the load vs midspan deflection
curve and, cracking pattern and mode of failure of the
bed.

In terms of dynamic performance ferrocement
bed has high natural frequencies and damping ratios
(see Table 4). The first resonance in ferrocement bed
occurred at almost twice the frequency of cast iron and
damping ratios of ferrocement were almost twice of
those for cast iron. Thus ferrocement bed may be
more stable when compared to cast iron bed.

Fig. 8  Deflected shapes of the bed under a point load

Fig. 9  Load deflection curve for ferrocement bed
Table 4  Modal parameters of Cast iron and ferrocement bed

<table>
<thead>
<tr>
<th>Mode of vibration</th>
<th>Cast Iron</th>
<th>Ferrocement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_1$ (Hz)</td>
<td>$f_2$ (Hz)</td>
<td>$f_3$ (Hz)</td>
</tr>
<tr>
<td>1st Vertical bending</td>
<td>342</td>
<td>280</td>
</tr>
<tr>
<td>1st Horizontal bending</td>
<td>252</td>
<td>310</td>
</tr>
<tr>
<td>2nd Torsional</td>
<td>125</td>
<td>465</td>
</tr>
<tr>
<td>2nd Vertical bending</td>
<td>730</td>
<td>620</td>
</tr>
<tr>
<td>2nd Horizontal bending</td>
<td>430</td>
<td>670</td>
</tr>
<tr>
<td>2nd Torsional</td>
<td>382</td>
<td>785</td>
</tr>
</tbody>
</table>

Fig. 10  Cracking pattern of the ferrocement bed after failure

Fig. 11  Lathe machine

Fig. 12  Cutting test results

The stability of a machine tool against chatter is one of the most important criteria to evaluate the performance of a machine tool. Two identical center lathes (shown in Fig. 11), one assembled with ferrocement bed and the other with cast iron bed were used in carrying out the test for comparative study. The lathe with ferrocement bed demonstrated higher stability reflected by the cutting test results shown in Fig. 12.

Despite possessing better dynamic properties, ferrocement could not find a suitable place as a replacement material of cast iron. Because, the fabrication process of ferrocement is quite labor intensive and time consuming due to the difficulty in cutting, bending and tying of fine wire mesh in the form of cages.

2.6.2 Fiber reinforced cement composites
Brittle failure is an inherent property of cementitious materials, and one way to overcome this problem is by using reinforcing fibers in the mix, known as fiber reinforced cement composite, it represents a class of cementitious materials obtained by adding short and discrete fibers of small diameter. These fibers are capable of interfering with the propagation of micro-cracks that initiate from the initial flaws in the material and forcing them to deflect thus dissipation additional energy during propagation. This delays the formation of an unstable crack system and thus, increases the tensile strength and toughness of the composite material [37][38].

Fibers are the load-carrying component of the composite. In general, they are characterized by near crystal size diameters and very high length to diameter ratio. Fibers can be organic, inorganic, synthetic and metallic. Composites can also be made of continuous fibers (usually called filament). Continuous filaments such as glass, carbon and aramid fibers are used almost exclusively in structural applications [50]. The matrix in the composite serves to bind the fibers together, protect them, and transfer load among fibers through shear.

The production process can be considerably simplified if the wire mesh in ferrocement is replaced by discrete steel fibers of short length and small diameter. These fibers can be added to the concrete while mixing the ingredients, and the resulting concrete can be directly poured into the mould.

The column of a grinding machine model PSG-52DX of Okamoto machine tool co. was designed, fabricated and evaluated by National University of Singapore and it was made with steel fiber reinforced cement composite (SFRC) [27][28]. The photograph of the SFRC column is shown in Fig. 13.

The cement composite mix selection was based on the results of preliminary tests on small specimens. Based on the findings of the investigation a normal mortar matrix (the ratio of cement, sand and water was 1:2:0.475) with 3% volume fraction of steel fibers was recommended for fabrication of prototype structural component of a machine tool. It has been shown from the performance studies that SFRC column was marginally less rigid than cast iron column.
due to dimensional constraints. Figure 14 shows that in the lateral direction, a load of about 12 kN produced a deflection of about 3 mm for the SFRC column and about 1.22 mm for the cast iron column. In the cross direction the deflections value were about 1.65 mm and 0.61 mm for concrete column and cast iron column, respectively, for the same load. In actual working conditions, the column is not subjected to such a high load. The actual grinding force is only a few hundred Newton's. The deflections produced by the actual loading conditions will therefore be very small to have any drastic effects on machining accuracy. But the damping ratios of the SFRC column was found to be significantly increased (see Tables 5 and 6) by about three times than those of the cast iron column and, for natural frequencies, no significant differences exist between the two columns. Figure 15 shows the dynamic test set up for SFRC column.

With the advantages of low cost, simple manufacturing process and good dynamic properties, steel fiber reinforced cementitious composites can be considered as a suitable material to replace cast iron for fabrication of machine tool structures.

<table>
<thead>
<tr>
<th>Resonance No.</th>
<th>Mode shape</th>
<th>Concrete</th>
<th>Cast Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First bending</td>
<td>F_c (Hz)</td>
<td>F_c (Hz)</td>
</tr>
<tr>
<td>2</td>
<td>Torsion</td>
<td>1.91</td>
<td>4.32</td>
</tr>
<tr>
<td>3</td>
<td>Second bending</td>
<td>0.88</td>
<td>6.00</td>
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</table>

<table>
<thead>
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<th>Resonance No.</th>
<th>Mode shape</th>
<th>Concrete</th>
<th>Cast Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tension</td>
<td>3.03</td>
<td>1.61</td>
</tr>
<tr>
<td>2</td>
<td>First bending</td>
<td>5.88</td>
<td>3.42</td>
</tr>
<tr>
<td>3</td>
<td>Second bending</td>
<td>0.28</td>
<td>9.39</td>
</tr>
</tbody>
</table>

2.6.3 Microfiber-reinforced cementitious composites—present new attempt Fibre reinforced cementitious composites have made striking advances in recent years. Although, the utilization of the large steel fibers (lengths between 20 to 60 mm and diameter 0.3 to 1.0 mm) has produced a composite with significantly improved toughness or ductility, the tensile strength of the host matrix is not changed dramatically. The reason often proposed for this incapability of the large fibers to improve the tensile strength is that the tensile failure is initiated at the micro-cracking level followed by progressive coalescence of micro cracks into micro cracks and the large steel fibers are too far apart to arrest, deflect, or blunt these micro cracks in any significant way. However, once the matrix is cracked, the large steel fibers promptly form stress transfer bridges across these cracks and provide a toughening mechanism through resistance to pull out and further crack opening. It may be hypothesized that very fine fibers (herein called ‘micro-fibers’), which would effectively modify the behavior of cracks at the micro level, may be expected to improve the tensile strength of cement-based materials[41][42]. Further, micro-fiber are able to provide reinforcing mechanism at the micro level such that the matrix cracks are arrested and stabilized before they acquire unstable dimensions.
The feasibility study of micro fiber reinforced concrete as a machine tool structure has been carried out at NUS. The high modulus polyvinyl alcohol (PVA) fiber (Cut length 6 mm, diameter 14 μ) is used in this experiment. In application to cement paste, the PVA fibers are highly effective in increasing the flexural strength and toughness characteristics and impact resistance of the material. A series of static and dynamic tests have been conducted to find out the most suitable design mix of micro-fiber reinforced cement composite, which possesses many beneficial properties for fabricating machine tool structures. Further latex is used as an additive for enhancing the vibration damping capacity of cement composites. A grinding machine column has been designed and fabricated using the developed cementitious composite and its performance has been evaluated. Test results revealed better dynamic properties for micro-fiber reinforced cement composite column than cast iron column. Both of the columns are shown in Fig. 16.

3. Conclusions

Incremental improvements need to be made on a continuous basis to improve the productivity and accuracy capability of machine tools. Effort needs to be directed at research to explore whether a major change in the structure of the machine tool can lead to significant improvements in properties that impact both productivity and accuracy.

The authors tried to render the knowledge about the most common machine tool structural materials. Merits and demerits of those materials are examined and compared to cast iron, the most commonly used machine tool structural material. It is concluded that each material has its own limitations. Among those cementitious composite materials particularly fiber reinforced cementitious composites have obtained a great interest due to their low cost, simple manufacturing process and satisfactory static and good dynamic properties.

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JSME International Journal
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