ABSTRACT

High structural stiffness and high damping are two essential functional requirements of machine tool structures of high-speed precision machine tools to manufacture accurate parts with reduced cycle time. Simultaneously both the attributes can never be accomplished since the conventional metallic materials such as steel and Cast Iron (CI) that is employed in development machine tool structures exhibits higher magnitude of stiffness and with a minimum damping ratio. In recent times, several novel composites such as polymer concrete, cement concrete, cement composites, epoxy granite and synthetic fiber reinforced composites and other advanced materials are preferred in the development of machine tool structures due to their improved mechanical (specific stiffness) and dynamic (damping) properties. Processing methods for conventional materials (foundry operations) and composites reinforced with synthetic fibers, however, involve high production costs and are dangerous to human health and environment. Pebbles can be used to make composites to overcome the above problems.

The main objective of this research is to explore the application of Epoxy Pebble (EP) as an alternate material in comparison with conventional materials towards the development of machine tool structures. Test specimens using epoxy resin and pebble aggregates with fillers have been manufactured.

The pebble: epoxy resin proportions by weight adopted are 65:35, 75:25 and 85:15, with aggregate sizes in the ranges 4-9 mm, 10-12 mm and 13.2-16 mm. Filler of sizes in the ranges 20-250µm, 300-630µm and 710-1000µm were used in this investigation. The matrix material, namely, epoxy resin (LY 556) in combination with hardener (Araldite 951) were identified as binding material. The weight fraction of epoxy resin to hardener used is 10:1. Curing durations of 8, 16 and 24 hours were employed. Characterization of

mechanical, dynamic, thermal and environmental properties of the EP composites developed was performed. Taguchi's design of experiments was adopted for the characterization.

Mechanical and dynamic test results indicated that use of coarse, medium and fine aggregates and lesser epoxy resin content leads to high strength and damping ratio. The X-ray diffraction results showed the presence of silicone oxide, quartz and nickel oxide. Major elements are presented and peak angles are identified. The effect of the chemical treatment of EP composite was confirmed by the FTIR analysis. The epoxy pebble composite with a weight fraction of 15% epoxy resin and 85% pebble aggregates was found to possess a higher value of compressive strength of up to103.96 ± 0.13 MPa and a damping ratio of 0.0169 ± 0.0009 compared to other compositions. Modal analysis was performed using the half-power bandwidth method. The damping ratios of EP composites were found to be between 5 and 10 times that of cast iron.

Flexural and split tensile strengths of the test samples were evaluated at different curing time durations, viz., 8, 16 and 24 hours. An increase in the resin content was observed to increase the flexural strength. The split tensile strength was found to increase with lesser resin content (85:15). However, in the case of pebble size, both flexural and split tensile strength values were found to decrease with increasing pebble size. The composite with 65 % of aggregates and 35 % of epoxy resin gives a better flexural strength (36 ± 0.46MPa). The higher split tensile strength (10.8 ± 1.24MPa) is attained in the composition of 85% of aggregates and 15% of epoxy resin.

Based on the experimental investigations on the mechanical and dynamic characteristics and from the study of Scanning Electron Microscope (SEM) image, it was found that the composite with an aggregate mixture of 85% and resin of 15% by weight provides better compressive strength

(103.96 ± 0.13MPa), damping ratio (0.0169± 0.0001) and split tensile strength (10.8 ± 1.24MPa). The composite with 65 % of aggregates and 35 % of epoxy resin gives a better flexural strength (36 ± 0.46MPa).

Transient Plane Source (TPS) techniques were used to determine effective thermal conductivity of the EP material. Effective thermal conductivity is observed to decrease with an increase in the epoxy resin content in the composite. The effective thermal conductivity of the EP composite was found to vary from 1 to 2 W/mK. The composite of 65% of aggregates and 35% of epoxy resin was found to possess lower thermal conductivity (1.531± 0.5 W/mK) and lesser voids (1.11 ± 1.4 %), whereas, lower water absorption was found to be possessed by the composite with 85% of aggregates and 15 % of epoxy resin.

S / N ratio and ANOVA were used to determine the significance and effect of the process parameters on the compressive strength, damping ratio, flexural and split tensile strength, thermal conductivity, water absorption and porosity of the composites developed. Confirmatory test was also conducted with the optimized level of attributes, and further the experimental results were compared with the predicted values by S / N ratio methods. The standard deviation was found to be within ±5 %.

Multi-attribute decision-making technique, viz., Grey Relational Analysis (GRA) is employed to determine the optimal process parameter combinations. The optimal set of process parameters are: proportion of pebble and epoxy by weight 85:15, aggregate size range 4-9 mm, micro filler size range 300- 630 μm and curing time of 16 hours.

As an outcome of the investigations carried out, a new material, namely, EP composite, has been identified, which can be used as a substitute for cast iron structures in machine tools. The newly developed EP composite has been found to possess good compressive strength and damping ratio. Further, the material developed is found to have low thermal conductivity, and hence structures made of the material will have high thermal inertia, which is a desirable property for machine tool structural materials. The water absorption and porosity of the material are also found to be low. All the aforementioned aspects indicate that the material developed is a suitable material for machine tool structures. However, the material is found to be poor in respect of flexural and tensile strength. Thus, since the compressive strength of the material is good, it can be concluded that this material could be highly preferred in development of machine tool structures such as machine tool base, columns and micro lathe bed without any trade-off among static and dynamic characteristics. Thus, within the scope of the study, it is established that EP is an appropriate alternative material for cast iron to make machine tool structures.

With the determined optimal process parameter combinations, an EP micro lathe bed was designed and fabricated. Results of numerical investigations are validated with the experimental tests on the EP lathe bed The numerical results bed agree well with the experimental results. The damping ratio of the EP lathe bed was found to be nearly three times that of the CI micro-lathe bed. The harmonic response of the EP micro lathe bed (0.0001 μm) is lesser in amplitude compared to CI bed (1 μm) throughout the frequency range tested.

From this research investigation, the novel EP material proves to be an ideal alternate material for cast iron material. Improved precision (higher damping) , improved productivity (improved dynamic stability will enable machining at higher cutting speeds) and enhanced tool life (due to higher damping) are the expected benefits of using the developed material for machine tool structures.