Preparation and application of a new material used in precision machine tool based on uniform design

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Abstract. With the rapid development of high-precision machining technology, materials used in foundation structure of machine tool plays an important role in alleviating vibration and keeping machining precision. In this article, a new material design and the corresponding simulation analysis of resin concrete is proposed to satisfy the requirements of machining accuracy. Uniform design method is used in the optimization of formula to reinforce the strength. On that basis, the contrast finite element analysis for mechanical parts made of resin concrete and cast iron are conducted respectively, and their different dynamic performances are acquired by modal analysis. Experiments show that the optimal design has better compression strength, mechanical part made of resin concrete has advantages of dynamic performance, which is suitable for the requirement of vibration reduction.

Introduction

With the development of modern machining technologies, high-precision machining has became a new trend in the field of mechanical engineering [1]. High-precision machining is no longer restricted in important national defense or aerospace field, which could provide traditional civilian mechanical products of better surface quality. However, vibration generated in the machining process has much more influence on the quality of the work piece. How to minimize vibration during manufacturing process is now an important factor that affects machining accuracy.

With good machinability and high strength, cast iron is the most widely used materials for the foundation structure in machine tool. However, its dynamical characteristics and heat stabilities have limits for the improvement of precision and cutting speed. Research and development of some other proper material with better dynamical properties would take the place of cast iron for elementary machine tool parts in the future [2].

Resin concrete is a new material that the research of it begins from Germany. H. Schulz firstly research of a high-speed milling machine that its tool bed is made of resin concrete in order to save steel consumption [3]. Resin concrete use cobblestones as aggregate and resin as binder that it has six times the damping properties, which can better reducing carbon emissions than cast iron. However, its application is restricted by its limitation in mechanical strength, and further research should be done.

Considering the fact that a large number of factors influence the macro properties of resin concrete, in order to improve the mechanical strength, a new preparation design method is proposed and uniform design method is used in the optimization of formula. The corresponding simplified assumption is conducted and the contrast finite element analysis for mechanical parts made of resin concrete and cast iron are conducted respectively. Their different performances are acquired by modal analysis to simulate their practical application. On that basis, the corresponding verification experiments are designed, and the compression strength testing of representative samples are measured to validate the aforementioned assumptions.

Experimental Procedures and Modeling

Uniform design scheme.

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For the characteristic that traditional "trial-error" method needs a large number of experiments to determine the optimum material compositions, uniform design is applied in the design and forming process of resin concrete in this article. Uniform design belongs to quasi monte-carlo category, which applies traditional single variable solution to the calculation of multivariable problem. The site selection in testing range spread evenly that as fully informations can be acquired by the least times of experiments [4].

Aggregate and resin are the main component in resin concrete. In order to better reduce segregation phenomenon, aggregate is subdivided into high-level coarse, low-level coarse, high-level fine and low-level fine aggregate by reasonable separation. The uniform design table used in formula design here is $U_{16}^{*}(16^{12})$, and the degree of uniformity is 0.1705, the uniform design scheme is shown in Table 1. Compression strength testing of representative samples are used as the assessment parameter. Regression analysis is used to get the error analysis of each components. Extremum fitting method is used to get the reasonable range.

Table 1 Uniform design scheme of resin concrete

	X_1	X_2	X_3	X_4	X_5
1	29%	15%	10%	37%	9%
2	45%	21%	11%	9%	14%
3	27%	10%	12%	32%	19%
4	43%	16%	13%	21%	7%
5	25%	22%	14%	27%	12%
6	41%	11%	15%	16%	17%
7	23%	17%	16%	39%	5%
8	39%	23%	17%	11%	10%
9	21%	12%	18%	34%	15%
10	37%	18%	19%	6%	20%
11	19%	24%	20%	29%	8%
12	35%	13%	21%	18%	13%
13	17%	19%	22%	24%	18%
14	33%	25%	23%	13%	6%
15	15%	14%	24%	36%	11%
16	31%	20%	25%	8%	16%

Preparation of samples.

Aggregates used for resin concrete are cobblestones. Organic resin applied is CYD115. Acetone is used as the diluent to make the resin less mucous. A series of resin concrete samples are prepared in cube form with 100mm length, 100mm width and 100mm height. The preparation of samples is composed of the forming process and machining process after samples are formed. Cobblestones are dried before weighing. Both resin and cobblestones are mixed together to set on the vibration table. Vibration lasted for 20 minutes after the mixing process ended.

Simulation modeling.

In order to get the variation trend between resin concrete and cast iron, several simplified assumptions are proposed for the simulation convenience. The density of resin concrete is defined as 1/3 of cast iron, and it's Young's modulus is defined as 1/4 of cast iron [5]. Geometrical models are built in ANSYS, as shown in Fig.1. Thin-wall structure is used for part made of cast iron under the same stiffness condition. The model analysis of 1st order are as shown in Fig.2.

In order to ensure the accuracy of simulation results, solid95 element in ANSYS is used in the model to get higher accuracy and better fit for irregular shape. HT200 is used to simulate cast iron whose density is defined as 7.8g/cm^3, its young's modulus is defined as 1.44×10^5 MPa and the passion's rate is 0.3. The density of resin concrete is defined as 2.3g/cm^3, its Young's modulus is defined as 0.42×10^5MPa, and its Passion's rate is defined as 0.2. Fixed boundary conditions is applied to the bottom corners of the model while 1000N concentrated force is applied to the top of the model.

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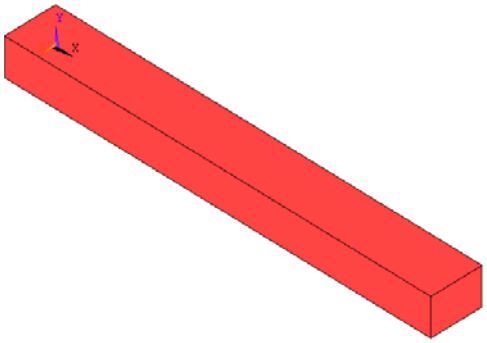

Fig.1 Model built in ANSYS

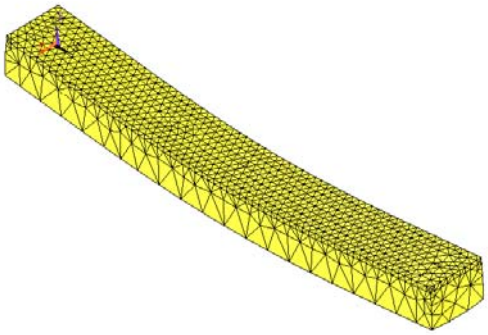

Fig.2 Model analysis of 1st order

Results and discussion

According to the testing results corresponding to Table1, the regression equation between the compression strength Y and each components are shown as:

$$Y = 66.595 + 1.335X_1 + 0.33X_2 + 0.0241X_3 + 2.295X_4 - 0.02X_1^2 - 0.01X_2^2 - 0.05X_3^2 - 0.065X_4^2 \quad (1)$$

The error analysis of the regression equation is shown in Fig.3. It is indicated that only the scheme 12 is a singular point, which can be eliminated. The distribution of all the other schemes are uniformly. The regression equation is $\alpha = 0.05$ highly significant.

Function of fminsearch is used in MATLAB to get an optimal fitting extremum, and the mass fraction of each components are shown below, which means the best compression strength is acquired while the mass fraction of aggregate and resin are 87.95% and 12.05% respectively.

$$\begin{cases} X_1 = 33.375\%, X_2 = 16.500\% \\ X_3 = 17.650\%, X_4 = 20.425\% \end{cases} \quad (2)$$

$$X_5 = 12.050\% \quad (3)$$

According to the above simulation results, under the same load condition, the max displacements of the part made of cast iron and resin concrete are 1.143mm and 0.769mm respectively. By analyzing the data in the Fig.4, it can be got that the natural frequency of part made of resin concrete is evenly increased a lot comparing with the full cast iron part, which will largely improve the safety property and machining precision of machine tools.

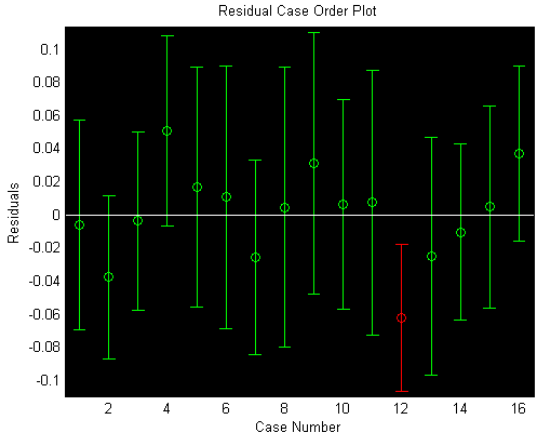

Fig.3 Error analysis of regression equation

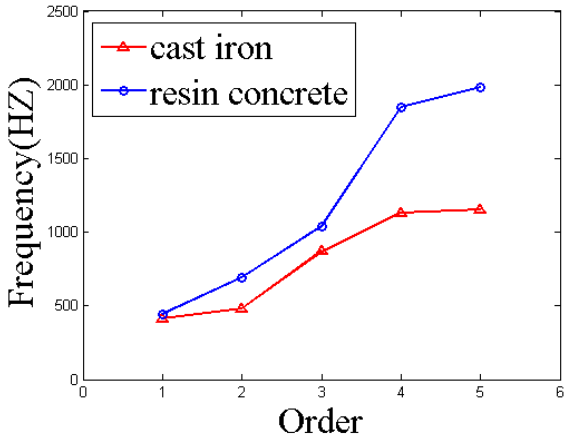

Fig.4 Contrast of natural frequency

Conclusions

(1) The uniform design is an useful method that it can be used in the future optimization research of materials, which can further reduce the experimental repeat rate.

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(2) The maximum compression strength can be acquired while the mass friction of aggregate and organic resin are 87.95% and 12.05% respectively.

(3) Compared with cast iron in the same rigidity, resin concrete has smaller displacement and higher natural frequency, which will largely improve the safety property and machining precision of maching tools.

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