Designing Machine Tool Structures With Epoxy Concrete

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Abstract:

The materials used in the manufacture of machine tools structures affects the metal removal rate; accuracy and surface finish of the products. The materials, in turn, have influence over the method of production, lead times and overall costs of the machine tool structures. Over a period of time machine tool builders relied on conventional materials, for the fabrication of machine tool structures, which have some inherent disadvantages. Those disadvantages have led researchers to investigate alternate materials for machine tool structures. Different non-conventional materials are being tried out globally for machine tool structures. Epoxy concrete is one of them, which has been developed at Central Mechanical Engineering Research Institute (CMERI), Durgapur and effectively utilized in precision machine tool and allied structures.

The development comprises the evaluation of different process parameters and the process know-how for the technology. The process parameters are both qualitative and quantitative in nature. The present paper describes the evaluation of one of the quantitative parameters i.e. ultimate compressive strength of epoxy concrete. For experimentation, Four-factor Factorial Design of Experiments was utilized. Test specimens were cast following the design of experiments and data were generated. The data were analyzed using Yates' Method and other statistical tools.

Keywords: Epoxy Concrete, Machine Tool Structure, Structural materials, Compressive Strength

1. INTRODUCTION

Non-conventional materials are the emerging demand for machine tool structures, while smooth operation has been hindered due to vibration and thermal deformation of machine tool structures, especially in precision machining [1]. To support the ever-increasing cutting speeds of modern machine tools, the machine tool builders are constantly in search of alternatives to conventional engineering materials like gray cast iron, mild steel, etc. due to its some inherent disadvantages like long manufacturing lead time, low damping, a tendency to rusting, high cost, etc. The alternative materials investigated so far include: granite, polymer concrete, synthetic granite, ferro-cement, fiber-reinforced cement composites, ceramic resin concrete, etc [2]. Although various degrees of success have been achieved with each material but some problems still exist.

In the light of this situation, a non-conventional material called Epoxy Concrete was developed at CMERI, Durgapur after an extensive R&D work and effectively utilized in precision machine tools structures like Surface Grinding Machine, Precision Cylindrical Grinding Machine, etc. Epoxy concrete is defined as a cold curing mixture of a reactable epoxy resin-hardener system (Binder) and a graded aggregate system (Filler), which can be poured into mould and then vibrated for a few minutes for compaction. The process is repeated till the mould is completely filled up. It is then cured for about 24 hours at room temperature and de-moulded to get the near net-shaped product as a alternative to cast iron or steel.

The production of high-precision machine tool structures demands some quality of the used epoxy concrete composite. The requirements to be met by the epoxy concrete are high mechanical strength and modulus of elasticity, low shrinkage, high damping properties, less moisture absorption, high chemical resistance, etc. Epoxy concrete machine tool structures are not usually reinforced like cement concrete structures. So to satisfy the mechanical strength criteria [3], the material must have high compressive strength as well as high tensile strength [4]. Evaluation of the ultimate compressive strength of epoxy concrete has been dealt with in this paper.

2. EXPERIMENTATION

To evaluate the compressive strength of epoxy concrete, the compressive test specimen (Fig.1) was selected as per "ASTM C 39-72" and a split steel mould was fabricated accordingly. Stone chips, sand and cement were used as fillers. Epoxy resin with hardener was used as binder. The fillers were collected from local market and binder was obtained from M/s. Hindustan Ciba-Geigy Ltd., Mumbai. For this evaluation only the proportion of fillers (Table 1) was varied and that of binder was kept constant throughout the experiments. Experiment was designed as per Factorial Design of Experiments using two levels of each factor and consequently the number of experiments needed was $2^3 = 8$. The treatments are *(1), a, b, ab, c, ac, bc*, and *abc* [5]. The experiments were replicated and then randomized [5]. Table 2 shows replicated 2^3 Factorial Design in randomized order.

Fig. 1: Test Specimen

Table 1: Factors and Their Levels

Factor	Factor Code	Level, kg	
		Low	High
SC	A	0.750	1.000
Sand	B	0.280	0.450
Cement	C	0.080	0.210

Table 2: Replicated 2^3 Factorial Design in Randomized Order

Serial No.	TC	Serial No.	TC
9	*c*	16	*abc*
1	*(1)*	2	*(1)*
7	*ab*	15	*abc*
11	*ac*	3	*a*
6	*b*	14	*bc*
4	*a*	12	*ac*
5	*b*	8	*ab*
10	*c*	13	*bc*

The diameter of the compressive test specimen was 75.00 mm and height 150.00 mm. As the size factor is 0.30 for maximum end properties [6], so the size of the stone chips selected was (75.00x0.30)mm = 22.50mm. This is according to the size of nearest available IS Test sieves (IS: 460 (Part I)-1985) of 20.0 mm and 25.0 mm. The size of sand used was (355-500)µm. 16 test specimens were cast as per experimental layout of Table 2. The test specimens were then mounted (Fig. 2) one by one in the Universal

Tensile Testing Machine (UTM-T 42 B) of capacity 50 T and load applied till failure. The ultimate compressive load for each specimen was recorded and divided by the corresponding cross-sectional area to get the ultimate compressive strength. Test results are shown in Table 3, where the mean values of compressive strength for different 'filler-binder ratios by weight' (FRW) are also presented. Fig. 3 shows the plot of 'mean compressive strength' vs. 'FRW'. To ascertain the effect of individual filler on the ultimate compressive strength, Yates' Analysis [5] has been carried out (Table 4).

Fig. 2: Experimental Set-up

Table 3: Data Summary of σ_c

TC	FRW (F/R)	σ_c N/mm^2	Mean σ_c N/mm^2
(1)	3.95	68.73, 67.56	68.145
a	6.31	71.19, 70.12	70.655
b	5.51	82.62, 81.15	81.885
ab	9.27	69.50, 69.00	69.250
c	5.19	85.67, 83.95	84.810
ac	8.62	81.25, 78.66	79.955
bc	**7.41**	**92.50, 91.30**	**91.900**
abc	13.80	65.99, 64.43	65.210

3. RESULTS ANALYSIS

The experiments were replicated to check the repeatability of the results and to find an independent estimate of the experimental error. The reason for randomization of experiments was to minimize the biasness of the experimenter and the influence of the experimental conditions (e.g. temperature, humidity, etc) and the instruments/apparatus used. The experimental graph shown in Fig. 3 indicates that the mean value of ultimate compressive strength increases with the increase of filler-binder ratio, reaches a maximum and then drops. However, the FRW= 5.51 and 6.31 do not follow the trend. Further experiments are necessary to check such discrepancy.

Yates' analysis of Table 4 shows that the most significant factor influencing the ultimate compressive strength of epoxy concrete is stone chips (A), followed by cement (C) and then by sand (B). The interactions AB, AC and BC are also highly significant indicating a non-linear relationship between factors A, B, C and σ_c.

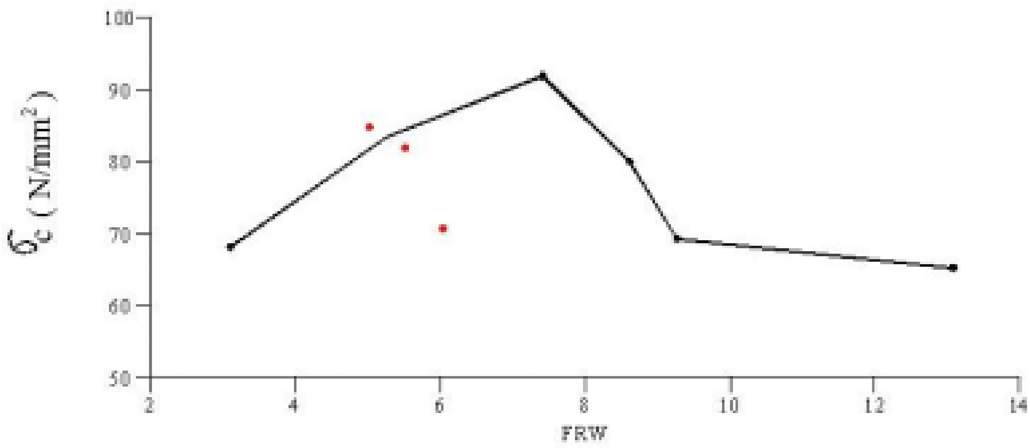

Fig. 3: Relationship between FRW and σ_c

The maximum compressive strength obtained in the experiment is 91.900 N/mm^2 corresponding to treatment *bc* and FRW of 7.41 (Table 3). To verify this value, a theoretical analysis was carried out. From 'Table 4' it is evident that the factor A exhibited the greatest negative effect of 10.42. In order to achieve increased ultimate compressive strength, the level of this factor must be reduced. A convenient step to reduce it would be 0.05kg, which comprises 1/5th of the range of this factor in the original experiment [(1-0.750)/5 = 0.05kg]. Factor B showed a positive effect of 1.17, thus this factor should be increased by steps of (1.17/10.42) x {(0.450-0.280)/5} = 0.0038kg. The factor C showed a more positive effect of 7.98. So this factor should be increased by steps of (7.98/10.42) x {(0.210-0.080)/5} = 0.0199 kg.

Thus the treatments to trace the path of optimum ultimate compressive strength, starting from the mid point [A=(0.750+1.000)/2=0.875 kg, B=(0.280+0.450)/2=0.365 kg and C=(0.080+0.210)/2=0.145 kg] are as shown in Table 5.

Table 4: Yates' Analysis for the Effect of Fillers on σ_c

TC	σ_c N/ mm^2	SOD of σ_c N/mm^2	Sum of σ_c N/mm^2	Yates' Analysis N/mm^2			MD N/ mm^2	t MD/ SE	P%	Effect	Rem -arks
(1)	68.73, 67.56	1.369	136.29	277.60	579.87	1223.62	152.95	-	-	Mean total	-
a	71.19, 70.12	1.145	141.31	302.27	643.75	-83.34	-10.42	19.40	<<0.1	A	VHS
b	82.62, 81.15	2.161	163.77	329.53	-20.25	9.36	1.17	2.18	≈5	B	S
ab	69.50, 69.00	0.250	138.50	314.22	-63.09	-73.96	-9.24	17.20	<<0.1	AB	VHS
c	85.67, 83.95	2.958	169.62	5.02	24.67	63.88	7.98	14.86	<<0.1	C	VHS
ac	81.25, 78.66	6.708	159.91	-25.27	-15.31	-42.84	-5.35	9.96	<<0.1	AC	VHS
bc	92.50, 91.30	1.440	183.80	-9.71	-30.29	-39.98	-4.99	9.29	<<0.1	BC	VHS
abc	65.99, 64.43	2.434	130.42	-53.38	-43.67	-13.38	-1.67	3.11	≈1	ABC	S
SM			1223.62	1140.28	1075.68	1043.36					

SM = Sum, SOD = Square of Difference
n = Number of Observations in each Replicate = 8
MD = Mean Difference, SD = Standard Deviation = $\sqrt{[\Sigma SOD/2n]}$
DF = Number of Degrees of Freedom = 8
SE = Standard Error of the MD = $\sqrt{[\{(SD)^2/DF\} + \{(SD)^2/DF\}]}$
t = Standardized Deviate = MD/SE, P% = Probability Percent
S = Significant, VHS = Very Highly Significant

Table 5: Treatments for Optimum Value

Treatment	1	2	3	4	5	6	7
A (kg)	0.875	0.825	0.775	0.725	0.675	0.625	0.575
B (kg)	0.365	0.3688	0.3726	0.3764	0.3802	0.3840	0.3878
C (kg)	0.145	0.1649	0.1848	0.2047	0.2246	0.2445	0.2644

The size of stone chips used for compressive test specimen was 20.0-25.0 mm for which the void volume ratio [7] is 0.571.

Void Volume Ratio = Void Volume/Mould Volume

Mould Volume = $\pi R^2 h = 15\pi(3.75)^2$cc = 662.68 cc
$\therefore$ 0.571 = Void Volume/662.68
Or, Void Volume = (0.571 x 662.68)cc = 378.39 cc

The 'void volume' is to be filled up by sand, cement and binder.
$\therefore$ Volume filled up by stone chips = Mould Volume-Void Volume
= (662.68-378.39)cc =284.29 cc

Weight of stone chips = Volume x Density = (284.29 x 2.870)gm = 815.912 gm = 0.816kg (approx). The maximum weight of SC that can be accommodated in the compressive test specimen mould is equal to 0.816kg. Only experiments 3, 4, 5, 6 and 7 of Table 5 would actually be carried out, since experiments 1 and 2 limit the maximum amount of stone chips for the mould size selected for compressive test. Each step change in the experimental conditions would be expected to contribute to the compressive strength as shown below:

Factor A: (10.42/10.42) x (10.42/5) N/mm^2 = 2.084 N/mm^2
Factor B: (1.17/10.42) x (1.17/5) N/mm^2 = 0.0263 N/mm^2
Factor C: (7.98/10.42) x (7.98/5) N/mm^2 = 1.2223 N/mm^2

Total contribution for three factors are (2.084+0.0263+1.2223)N/mm^2= 3.3326N/mm^2. The mean values of each factor give the starting point to trace the path of optimum compressive strength. Each incremental step along the path should increase the compressive strength by 3.3326 N/mm^2. If five steps are applied after the limiting amount of stone chips that can be accommodated in the compressive test mould, the compressive strength should be increased by 3.3326x5=16.663N/mm^2. Since the mean compressive strength in the original experiments was (1223.62/16)N/mm^2 i.e. 76.476N/mm^2 (Table 4), the maximum compressive strength would be about (76.476+16.663)N/mm^2= 93.139 N/mm^2. The experimental value obtained was 91.900N/mm^2, which is less than the anticipated optimum value by 1.35%. For confirmation of the calculated optimum value, for treatments 3, 4, 5, 6 and 7 of Table 5, requires further experimentation.

4. CONCLUSIONS

1. The most significant factor influencing the ultimate compressive strength of epoxy concrete is stone chips (53.24%), followed by cement (40.78%) and then by sand (5.98%).
2. The maximum value of ultimate compressive strength obtained is 91.900 N/mm^2 corresponding to the filler-binder ratio of 7.41.
3. The proportion of stone chips, sand and cement (treatment *bc*) which produced maximum compressive strength is 3.57 : 2.14 : 1.

4. The observed optimum compressive strength is nearer to the predicted optimum value of 93.139 N/mm^2, the deviation being 1.35%.
5. The presence of strong interactions between the factors indicates a non-linear relation between them and the ultimate compressive strength.

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6. NOTATION

F	Filler = Stone Chips (SC) + Sand + Cement
TC	Treatment Code
σ_c	Ultimate Compressive Strength
R	Binder = Epoxy Resin + Hardener
FRW	Filler-Binder Ratio by Weight = F/R

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