Jurnal Mekanikal
Dec 2016, Vol 39, 11-15

USING TAGUCHI, PCR-TOPSIS AND GENETIC ALGORITHM TO OPTIMISE OF DIAMETRAL TENSILE STRENGTH AND DENSITY OF PMMA-ZIRCONIA COMPOSITE

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ABSTRACT

Acrylic bone cement of PMMA (poly-methylmethacrylate) have been used for more than 40 years in dental implant and orthopedic surgery for the fixation of artificial joints. Zirconia (ZrO_2) has been widely used in medical application because of their chemical and physical properties such as good mechanical strength and good thermal stability. In this study, acrylic bone cement reinforced with bioceramic was prepared by mixing beads of PMMA and ZrO_2 powder. Diametral tensile strength and density were tests to determine the mechanical properties of PMMA-ZrO_2 composite. Simultaneous optimization of diametral tensile strength and density of PMMA-ZrO_2 composite were done by Taguchi method, PCR-TOPSIS and genetic algorithm. Experiments have been carried out using Taguchi $L_{16}(4^5)$ orthogonal arrays. Experimental data have been transformed into new data set using SNR and PCR-TOPSIS. The new data set were used to find simultaneous optimization of DTS and density of PMMA-ZrO_2 composite using genetic algorithm. According to the hybrid method, global optimum of DTS and density of PMMA-ZrO_2 composite are 8.758 MPa and 68.8 %. This result occurred when 5 wt% ZrO_2 in PMMA, sintering temperature at 157^0C and holding time at 75 minutes.

Keywords : *PMMA-ZrO_2, Taguchi, PCR-TOPSIS, Genetic algorithm*

1.0 INTRODUCTION

The Acrylic bone cements of PMMA (poly-methylmethacrylate) have been used for more than 40 years in dental implantology for expansion of dental implants, maxillofacial prosthesis as gentamicin loaded beads, prosthetics for fixing partial dentures and orthopedic surgery for the fixation of artificial joints [1]. However, PMMA insufficient mechanical strength that easily broken during an accident or a patient applies high mastication force to the denture base [2]. Therefore, improvements are necessary to increase performance of a cemented prosthesis [1]. Bioceramics such as zirconia, alumina, glass ceramic have been widely used in medical applications due to their superior biocompatibility, aesthetics, mechanical resistance, corrosive resistance and easy fabrication of complex shapes [3]. Zirconia (ZrO_2) has properties such as chemical resistance, good mechanical strength and good thermal stability. In this research, acrylic bone cement reinforced with bioceramics was prepared by mixing beads of PMMA and ZrO_2 powder.

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Diametral tensile strength (DTS) and density are a critical requirement for acrylic bone cements [4]. These characteristics must be optimized simultaneously. Taguchi method is a systematic approach to design and analysis of experiments for robust optimization. However, the original Taguchi method has been designed to optimize a single quality response [5]. In order to overcome this problem, a multi-response prediction model based on the process capability ratio (PCR) and order preference by similarity to the ideal solution (TOPSIS) were proposed [6]. However, Taguchi and PCR-TOPSIS method are applicable only to selection of parameter values from discrete levels [6]. In the absence of global optimization tools, engineers are often forced to settle for feasible solutions, often neglecting the optimum values. The genetic algorithm approach provides the solution for the above problems. The objective of global optimization is to find the best possible solution in decision models that frequently have a number of local optimum solutions. Due to its random nature, the genetic algorithm improves the chances of finding a global solution. Genetic algorithm has proved to be very efficient and stable in searching for global optimum solutions [7]. This paper propose the hybrid method for simultaneous optimization of DTS and density of PMMA-ZrO_2 composite based on Taguchi method, PCR-TOPSIS and genetic algorithm.

2.0 MATERIAL AND METHODS

PMMA powder as received from Ortho (England) and ZrO_2 powder as received from Tosoh (Japan). Controllable factors in this experiment were A as weight percentage of ZrO_2 in PMMA (0 wt%, 1 wt%, 2 wt%, 3 wt%), B as sintering temperature (140^0C, 145^0C, 150^0C, 155^0C) and C as sintering holding time (60, 75, 90, 105 minutes). This experiment does not involve noise factors. Responses variable in this experiment are DTS and density. Orthogonal array $L_{16}(4^5)$ from Taguchi was used this experiment. In this orthogonal array there are 16 treatments. Each treatment performed 5 replication.

Experiment and static optimization procedure includes the following steps:

Step 1: Running the experiment randomly and record the response of each treatment.
The density of PMMA-ZrO_2 composites were measured using the Archimedes method. DTS testing of PMMA-ZrO_2 composites, specimen with 6 mm diameter × 3 mm high, were loaded at a crosshead speed of 5 mm/min until catastrophic brittle failure occurred.

Step 2: Determine the signal to noise ratio (SNR)
SNR formula is given as:

$$\eta = -10 \log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right] \quad (1)$$

Where, y is the i^{th} value of response in each treatments, n is the number replication.

Step 3: Determine the process capability ratio of SNR
Process capability ratio (PCR) of SNR can be found with the following formula:

$$C_j^i = \frac{\eta_j^i - \bar{x}_{\eta j}}{3 s_{\eta j}} \quad (2)$$

Where the sample mean formula for SNR in the j^{th} response is given as:

$$\bar{x}_{\eta j} = \frac{\sum_{i=1}^{m}\eta_j^i}{m-1} \quad (3)$$

And the sample standard deviation formula for SNR in the j^{th} response is given as:

$$s_{\eta j} = \sqrt{\frac{\sum_{i=1}^{m}(\eta_j^i - \bar{x}_{\eta j})^2}{m-1}} \quad (4)$$

Step 4: Determine TOPSIS of PCR-SNR
TOPSIS of PCR-SNR can be found with the following formula:

$$S^i = \frac{d^{i-}}{d^{i+} + d^{i-}} \quad (5)$$

Where the distance of the i^{th} trial from the ideal alternative is given as:

$$d^{i+} = \sqrt{\sum_{j=1}^{n}(C_j^i - C_j^+)^2} \quad (6)$$

And the distance of the i^{th} trial from the negative ideal alternative is given as:

$$d^{i-} = \sqrt{\sum_{j=1}^{n}(C_j^i - C_j^-)^2} \quad (7)$$

With,

C_j^+ = max{C_j^i, for i = 1, 2, . . . , m}, C_j^i (i = 1, 2, . . . , m, j = 1, 2, . . . , n) (8)

C_j^- = min{C_j^i, for i = 1, 2, . . . , m}, C_j^i (i = 1, 2, . . . , m, j = 1, 2, . . . , n) (9)

Step 5: Determine Z quadratic function of PCR-TOPSIS
Z quadratic function of PCR-TOPSIS be determined using nonlinear regression using statistical software. Z quadratic function is used as a fitness function in genetic algorithm.

Step 6: Finding the global optimum solution using genetic algorithm
A fitness function use to measure fitness such that solutions with a better fitness value have a higher probability of being selected for the next generation [6]. The fitness of candidate solutions is therefore improved with each new generation. Genetic algorithm procedure according to following step: initializing population, parent selection, crossover, mutation, preservation and termination.

3.0 RESULTS AND DISCUSSION

In this research, response variables were DTS and density. These responses will be transformed into a new data set using PCR-TOPSIS. Global optimum solution will be solved by genetic algorithm. The larger value of SNR showed the better results. Table 1 showed experiment data from orthogonal array L_{16} (4^5) design. Table 2 showed the value of SNR, PCR-SNR and distance for ideal solution. The SNR value was determined using equation 1. The PCR-SNR value was determined from step 3. The distance from ideal solution was determined from step 4.

Table 1: Result of experiment using orthogonal array L_{16} (4^5)

No	Control factor			DTS (MPa)					Relative Density (%)				
	A	B	C	1	2	3	4	5	1	2	3	4	5
1	1	1	1	2.47	3.12	2.82	3.28	3.26	0.62	0.57	0.66	0.63	0.78
2	1	2	2	6.51	6.64	6.74	7.49	6.70	0.66	0.65	0.66	0.67	0.66
3	1	3	3	6.81	6.81	7.09	7.26	8.01	0.54	0.55	0.59	0.67	0.63
4	1	4	4	1.80	6.00	4.05	2.31	3.28	0.55	0.53	0.55	0.54	0.57
5	2	1	2	0.42	0.43	0.47	0.61	0.54	0.68	0.64	0.66	0.67	0.68
6	2	2	1	1.04	1.00	1.54	0.95	0.75	0.58	0.57	0.57	0.60	0.55
7	2	3	4	0.82	3.73	5.94	8.43	7.58	0.67	0.65	0.63	0.66	0.63
8	2	4	3	4.30	5.92	2.85	6.36	3.13	0.57	0.61	0.55	0.65	0.59
9	3	1	3	2.16	2.60	1.45	1.88	2.17	0.60	0.56	0.68	0.54	0.65
10	3	2	4	1.00	1.08	1.07	0.51	0.64	0.51	0.58	0.54	0.56	0.53
11	3	3	1	3.99	4.66	5.23	5.17	5.66	0.64	0.64	0.62	0.65	0.63
12	3	4	2	4.86	3.16	4.27	2.77	4.72	0.60	0.56	0.63	0.60	0.57
13	4	1	4	1.78	1.29	2.34	1.12	1.31	0.53	0.52	0.55	0.56	0.53
14	4	2	3	2.23	2.07	1.63	2.43	1.65	0.58	0.60	0.59	0.60	0.55
15	4	3	2	6.31	4.09	4.44	5.18	5.33	0.67	0.64	0.64	0.65	0.67
16	4	4	1	2.88	2.35	4.38	4.97	5.04	0.64	0.51	0.60	0.57	0.60

Table 2: The value of SNR, PCR-SNR and distance from ideal solution

No	SNR		PCR-SNR		Distance	
	DTS	Density	DTS	Density	d^{i+}	d^{i-}
1	9.36	-3.84	0.06	0.43	0.40	1.08
2	16.64	-3.59	0.41	0.55	0.03	1.43
3	17.10	-4.58	0.44	0.07	0.50	1.22
4	8.67	-5.22	0.02	-0.24	0.91	0.74
5	-6.37	-3.55	-0.72	0.57	1.15	0.89
6	-0.21	-4.87	-0.41	-0.07	1.06	0.39
7	4.88	-3.80	-0.16	0.45	0.61	0.95
8	11.77	-4.61	0.18	0.05	0.57	0.97
9	5.74	-4.43	-0.12	0.14	0.70	0.76
10	-2.56	-5.29	-0.53	-0.27	1.28	0.19
11	13.69	-3.94	0.27	0.38	0.25	1.21
12	11.28	-4.59	0.15	0.06	0.58	0.95
13	3.04	-5.39	-0.25	-0.32	1.13	0.46
14	5.69	-4.71	-0.12	0.01	0.79	0.68
15	13.81	-3.70	0.28	0.49	0.18	1.29
16	10.62	-4.74	0.12	-0.01	0.66	0.89

Z quadratic function was determined using statistical software is given as:

$$Z = 0.517 - 0.456A + 0.202B + 0.421C + 0.064A^2 - 0.038B^2 - 0.084C^2 + 0.033AB - 0.004AC - 0.017BC \quad (10)$$

Parameters of genetic algorithm to finding global optimization are fitness function Z from equation 10, population size is 16, crossover probability is 0.6, mutation probability is 0.02 and preservation probability is 0.2. Maximum generation is 50 of factor and level setting of PCR-TOPSIS. Table 3 showed the entire optimization results that showed a generation with the best fitness value level and the average value of fitness. The optimum value reached in the generation of 40. Optimum setting level and factors are 5 wt% of ZrO_2, 157^0C sintering temperature and 75 minutes sintering holding time. Finally, the result of hybrid method were compared with Taguchi method and PCR-TOPSIS. Table 4 showed estimated optimum value of DTS and density at optimum setting level for 3 different methods. Estimated global optimum of DTS and density of PMMA-ZrO_2 composite using hybrid method are 8.758 MPa and 68.8 %.

Table 3: Genetic algorithm optimization

Generation	A	B	C	Best fitness	Mean fitness
1	4.6	4	1.9	0.913	0.668
2	4.6	4	1.9	0.913	0.717
3	4.6	4	1.9	0.913	0.795
..	..	..	..	..	
39	6	4.8	2	1.405	1.325
40	6	4.6	2	1.410	1.316

Table 5: Estimated optimum value of DTS and density

Method	Factor and level	Estimated optimum value	
		DTS	Density
Taguchi	A-1 : B-3 : C-2	-	0.685
	A-2 : B-3 : C-2	7.806	-
PCR-TOPSIS	A-1 : B-3 : C-2	7.806	0.681
Hybrid*)	A-6 : B-4.6 : C-2	8.758	0.688

*) Hybrid = Taguchi and PCR-TOPSIS and genetic algorithm

3.0 CONCLUSIONS

This research presents a hybrid method consisting of Taguchi, PCR-TOPSIS and genetic algorithm to find global optimum solution of DTS and density properties of PMMA-ZrO_2 composite. DTS and density data from Taguchi experiment were transformed into SNR to find a new variable by using PCR-TOPSIS. This variable and its quadratic function has been used to find global optimum solution using genetic algorithm. Optimum value reached at generation up to 40. According to hybrid method, global optimum of DTS and density of PMMA-ZrO_2 composite are 8.758 MPa and 68.8 % were occurred in 5 wt% of ZrO_2 in PMMA, 157^{0}C temperature and 75 minutes sintering holding time. Finally, hybrid method showed optimum results better than Taguchi method or PCR-TOPSIS.

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