K. RAMANATHAN, V.M. PERIASAMY[a], MALATHY PUSHPAVANAM[b], U. NATARAJAN*

Scientific paper
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Optimization of hardness of nickel diamond electro composites using genetic algorithm

Nickel-diamond composite coatings are produced by electro deposition using sedimentation technique at various cathode current densities, pH and temperatures. Electro deposition was carried out from a conventional Watts bath. Natural diamond powder of 6-12 μm size was used. The hardness of deposited electro composites were measured using Vickers hardness measuring machine. A non linear regression equation was developed using 27 data obtained by designing an experiment with three level of experiment namely Low, Medium and High to predict the hardness of deposition in Ni-diamond metal matrix. Optimization of parameters of Ni-diamond composite coating such as pH, current density and temperature was done using a non traditional optimization technique called as Genetic Algorithm (GA). Within the range of input variables for the present case (pH = 2.5 to 4.5; current density (i) = 1 to 3 A/dm^2; temperature = 30 to 60^{0}C), the optimized hardness was found to be 431.95 VHN at pH = 2.5 Current density (i) = 1 A/dm^{2}and temperature = 30^{0}C.

Key words: *hardness (VHN), regression model, Ni-diamond composite coatings, genetic algorithm (GA)*

1. INTRODUCTION

Particle-reinforced metal matrix composites generally exhibit wide engineering applications due to their enhanced hardness, wear and corrosion resistance compared to pure metal or alloy [1]. Composite electroplating has been identified to be a technologically feasible and economically superior technique for the preparation of such kind of composites [2].Over the last few years, successful co-deposition of micro-sized particles such as metallic powder, silicon carbides, oxides and diamond with metal have been reported and their corresponding structures and properties were investigated. Due to their extreme hardness, wear resistance, good thermal conductivity and low thermal expansion coefficient diamond finds applications as cutting tools. Research was carried out on diamond coated tool using various techniques such as PVD and CVD [3],[4]. Studies on Nickel-Diamond electro composite coatings are reported [5]-[9]. The volume percent incorporation of diamond powder in the Ni-cobalt-diamond composite coating measured gravimetrically was demonstrated [10]. The hardness of the deposited composite metal matrix is mainly affected by the process parameters such as current density, pH value, and temperature of the solution and concentration of diamond dispersed in the electrolyte.

Address authors: A.C. College of Engineering and Technology, Karaikudi 630 004, TN, India, [a] B.S.A crescent Engineering College, Vandalur, Chennai 600 048, TN, India, [b] Central Electro chemical Research Institute, Karaikudi 630 006, TN, India. * Corresponding author: E mail address: kalirams@yahoo.com

Genetic Algorithm (GA) is a search and optimization procedure that arrives at an optimal solution by generating a rich child from a parent mating pool. It mimics the principles of natural genetics to arrive at the optimal solution. GA operates on the principle of the 'Survival of the fittest', where weak individuals die before reproducing while stronger ones survive and bear many offspring and breed children who often inherit the qualities that enable their parents to survive. The reproduced children are stronger than their parents in most cases. The parameters of the function to be optimized are encoded as genes in a chromosome. A random population pool of individuals (chromosomes) is created. Then the pair of individuals is selected from this pool based on their performance. The selected pairs reproduce, creating children whose genetic structures share the characters of both the parents. Perhaps some mutations take place in the creation of child as in the nature. As the hardness of coated specimen is affected by parameters such as current density, pH value, temperature, it is very essential to estimate the above affecting parameters that enable the maximum hardness. Genetic Algorithm (GA) a powerful non traditional optimization technique is used in this study.

2. GENETIC ALGORITHM (GA)

Genetic algorithms are computerized search procedures based on the mechanics of natural genetics and natural selection that can be used to obtain global and robust solutions to optimization problems. Genetic algorithms are computational optimization schemes with an unconventional approach. The algorithms solve optimization problems of years on the evolution of life. Genetic algorithms combine survival of the fittest among string structures with a structured yet randomized information exchange to form a search algorithm with some of the innovative flair of human search. In every generation, a new set of artificial strings is created using bits and pieces of the fittest of the old; an occasional new part is tried for measure. Genetic algorithms differ from conventional optimization and search procedures in several fundamental ways as follows: (i.) GA work with a coding of solution set not the solution themselves; (ii) GA search form a population of solutions not a single solution; (iii) GA use payoff information (fitness function) of derivatives or other auxiliary knowledge; (iv) GA use probabilistic transition rules, not deterministic rules. Genetic Algorithms normally begin with a population of strings created randomly. There after, each string in the population is evaluated. The population is then operated by three main operators. (i) Reproduction (ii) Cross over (iii) Mutation. The population is further evaluated and tested for termination. If the termination criteria are not met, the population is again operated by the three operators and evaluated further. This procedure is continued till the termination criterion is met. One cycle of these operators and evaluation procedure is known, as a generation in GA terminology and the flow chart descrybing the above is shown in figure.1.

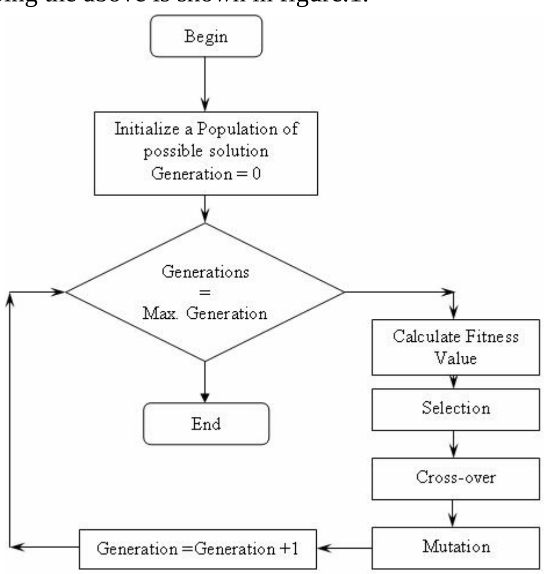

Fig. 1: Flow chart describing a cycle of GA generation

3. EXPERIMENTAL PROCEDURE

3.1 Plating bath

The conventional Watts bath of the following composition was used: Nickel sulphate: 250 g/l; Nickel chloride: 30 g/l; Boric acid: 40 g/l. The bath was purified in the conventional manner for removal of organic and inorganic impurities [11]. The pH value of the electrolyte was adjusted electrometrically using dilute H_2S_{O4} or KOH. 0.01g/l sodium lauryl sulphate was added to the electrolyte as anti-pitting agent before plating. The temperature of the electrolyte was maintained using a thermostat.

3.2. Plating procedure

Deposition was carried out on a 500 ml capacity using sedimentation technique [6]. Nickel anodes and mild steel cathodes were used. The cathodes of 7.5×2.5 cm area were mechanically polished, degreeased, bent to 90°, suitably masked to expose an effecttive plating area of 6.25 cm^2, electro cleaned, first cathodically and then anodically, washed rinsed and then introduced into the plating electrolyte with the area to be plated in the horizontal plane closer to the bottom of the cell facing the anode. A bagged nickel anode bent similarly was placed above the area to be coated. Diamond powder (6 to 12 µm) was added to the electrolyte in the form of slurry. The solution was stirred using a magnetic stirrer. Stirring was given initially for 30 s to bring all the diamond powder into the suspension and then stopped. The deposition was continued for 15 minutes to allow the particles to settle on the substrate while the deposition proceeded. The same process was repeated to obtain deposit thickness of 25 µm. The hardness of the coating was measured by Vickers hardness measuring machine. Specimen hardness is measured in four locations randomly and the values reported are the average of four readings.

3.3. Ni-diamond deposition

Natural grade polycrystalline diamond powder of 6–12 µm size was used. Prior to the co-deposition, the diamond particles were ultrasonically dispersed in the bath for 10 min. Experiments were conducted at a fixed diamond concentration of 5 g/l, varying the plating parameters like temperature, pH, and current density.

3.4 3^k Factorial Design for three factors

For the prediction of hardness value under a variation of coating conditions, a training database with regard to different coating parameters needs to be established. A number of Ni-diamond composite coatings were carried out on mild steel substrate. Ranges of coating parameters in the coating process are as follows: Current density, i = 1 to 3 A/dm^2 ; pH value = 2.5 to 4.5; Temperature = 30 to 60 ^{0}C. For the above combination of parameters, twenty seven numbers of Ni-diamond composite coatings were obtained and their hardness was measured using Vickers hardness measuring machine. The level designation of different process variables is shown in Table 1.

Table 1 - Level designation of different process (Coating) variables

Level	i (A/dm^2)	pH	T (^{0}C)
-1	1	2.5	30
0	2	3.5	45
1	3	4.5	60

4. OPTIMIZATION OF PARAMETERS USING GENETIC ALGORITHM (GA)

4.1 Problem Formulation (Objective Function)

For any optimization problem, the problem formulation is the first and foremost step. In the case of Nickel-diamond electro composite coatings, hardness is expected to be maximum and hence the present problem is an unconstrained maximization type problem. A non linear regression equation is formed using the 27 practical data obtained at the combinations of above three levels from Nickel-diamond electro composite coating by sedimentation technique and is used as an objective function for the present case. The objective function is as detailed below:

Maximization of Hardness

$$(VHN) = 1370.83\, pH^{-0.054} i^{-0.0241} T^{-0.325} \quad (1)$$

Genetic Algorithms are naturally suitable for solving maximization problems and hence the above objective function becomes a fitness function also.

4.2 GA Optimization

Basic steps of GA are (1) Initialization (2) Population evaluation (3) Reproduction (4) Cross over (5) Mutation.

4.2.1 Initialization

The first step in GA is to initialize the population. The initialization can be executed with either a randomly created population (or) a well adapted population. In this work, an initial population of 50 is generated randomly without any constraint.

4.2.2 Population Evaluation

Two important issues in the evaluation process of genetic search are population diversity and selective Pressure. i) Population diversity means that the genes from the already discovered good individuals are exploited while premising the new areas of the search space continue to be explored. ii) Selective pressure is the degree to which the better individuals are favored.

4.2.3 Reproduction

Reproduction is the first operator applied on population. Reproduction selects good strings in a population and forms a mating pool. There exist a number of reproduction operators in GA

Literature, but the average strings are picked from the current population and their multiple copies are inserted in the mating pool in a probabilistic manner. The Roulette- wheel method is used for the selection of chromosomes for parents to cross over.

4.2.4 Cross – Over

After the reproduction phase is over, the population is enriched with better individuals. Reproduction makes clones of good strings, but does not create new ones. Swapping of bits will take place in between two randomly chosen parent strings so that fitness value may be improved further. Single point crossover as illustrated in figure 2 is performed in the present study, where the two parents are cut at their center points, and the child chromosome is given the same combination of genes as the first parent in its outer half chromosome and the same genes as the second parent in the inner half chromosome. The probability of cross over is considered as 0.8. When crossover is not conducted, the parent is copied into the next generation. This procedure continues until the population is reached.

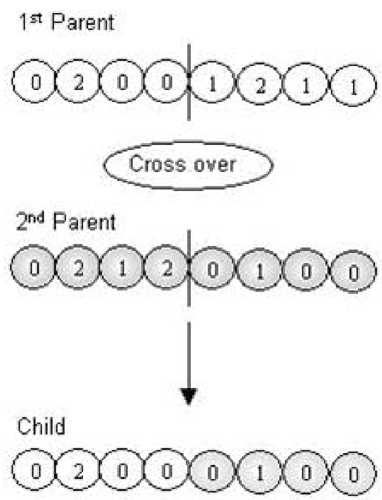

Fig. 2: Cross-over

4.2.5. Mutation

Mutation as it can occur in nature is also taken into account. But the probability of its occurrence is less. Mutation occurs only if the random number generated is less than the mutation probability 0.1. Mutation operator alters a chromosome locally to hopefully create a better string. Mutation of a bit involves flipping it, changing 0 to 1 and vice versa. The flow chart describing the Genetic Algorithm procedure involving all the above detailed operations is shown in figure 3.

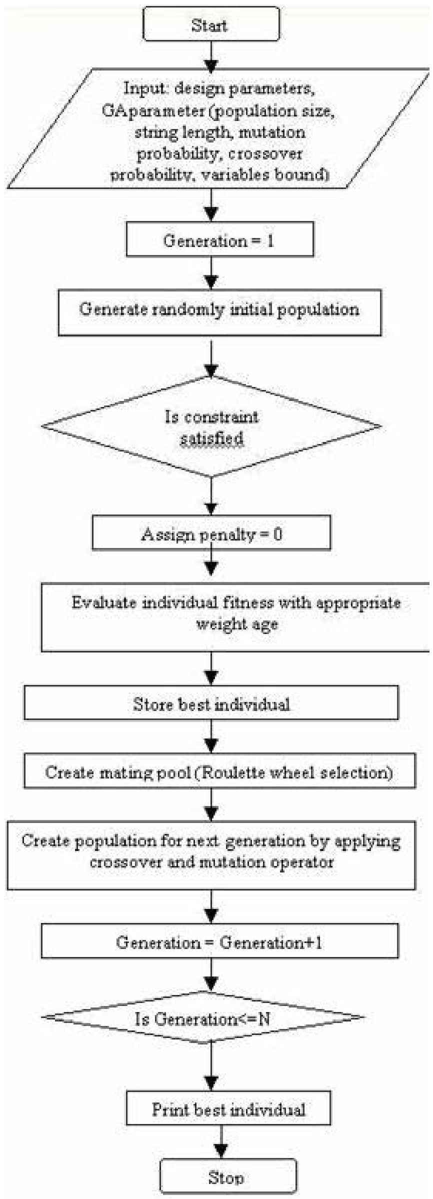

Fig. 3: Flow chart describing the Genetic Algorithm procedure

5. RESULTS AND DISCUSSION

5.1 Effect of Genetic Algorithm on Hardness

Effect of Genetic Algorithm on maximization of hardness i. e) Fitness value and their corresponding parameter values for each of the 50 population are shown in the table 2. The maximum hardness value (fitness value) in Nickel-Diamond composite coating was found to be 431.95 and it was obtained in the second generation among fifty generations. The corresponding parameters that maximize the hardness were determined as follows: pH=2.5; i=1 A/dm^2 and T=30 ^{0}C.

Table-2 - Effect of Genetic Algorithm on Maximization of hardness

Number of Generation	Maximum Fitness value (VHN)	Variables (pH,i,T)
	424.78	2.79, 1.57, 30.00
	431.95	2.50, 1.00, 30.00
	362.54	2.50, 1.00, 51.43
	397.39	3.36, 2.71, 34.29
	403.71	2.79, 2.14, 34.29
	419.94	4.21, 1.00, 30.00
	344.03	3.64, 1.29, 55.71
	331.31	3.36, 2.71, 60.00
	381.45	4.50, 1.57, 38.57
	337.13	4.50, 1.86, 55.71
	412.29	4.21, 2.14, 30.00
	381.45	4.50, 1.57, 38.57
	388.55	2.79, 2.14, 38.57
	354.87	2.50, 2.43, 51.43
	349.40	2.50, 1.57, 55.71
	413.86	3.93, 2.14, 30.00
	410.84	4.50, 2.14, 30.00
	339.72	2.50, 1.86, 60.00
	424.78	2.79, 1.57, 30.00
	341.93	3.07, 2.43, 55.71
	415.02	3.36, 2.71, 30.00
	330.43	4.50, 1.57, 60.00
	382.47	3.36, 2.71, 38.57
	410.84	4.50, 2.14, 30.00
	396.34	4.50, 1.57, 34.29
	427.27	2.50, 1.57, 30.00
	329.10	4.50, 1.86, 60.00
	349.40	2.50, 1.57, 55.71
	410.84	4.50, 2.14, 30.00
	413.92	4.50, 1.57, 30.00
	349.40	2.50, 1.57, 55.71
	354.87	2.50, 2.43, 51.43
	413.92	4.50, 1.57, 30.00
	339.38	3.36, 2.71, 55.71
	382.47	3.36, 2.71, 38.57
	421.68	2.50, 2.71, 30.00
	352.95	3.36, 1.57, 51.43
	381.45	4.50, 1.57, 38.57
	427.27	2.50, 1.57, 30.00
	373.97	4.21, 1.00, 42.86
	415.02	3.36, 2.71, 30.00
	403.71	2.79, 2.14, 34.29
	349.40	2.50, 1.57, 55.71
	410.84	4.50, 2.14, 30.00
	393.76	2.50, 1.57, 38.57
	341.33	4.21, 1.29, 55.71
	381.45	4.50, 1.57, 38.57
	338.49	4.50, 1.57, 55.71
	382.47	3.36, 2.71, 38.57
	330.51	3.36, 3.00, 60.00

6. CONCLUSION

A non linear regression model was developed for the unconstrained optimization of hardness in Ni-diamond composite coated metal matrix using 27 test data and it was used as objective function (Fitness function) in the maximization problem. For maximizing hardness and to estimate the affecting parameters such as pH, current density and temperature, a modern intelligent technique known as Genetic Algorithm approach was carried out. In order to increase the accuracy and also to reduce time, a programme is implemented on a PC using C language. Within the range of input variables for the present case (pH = 2.5 to 4.5; current density (i) = 1 to 3 A/dm^2; temperature (T) = 30 to 60^0C), the parameters that maximizes the hardness are pH=2.5, i=1 $A/dm^2$and T=30^0C and the maximized out put is 431.95VHN.

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