MODELING OF PRODUCTION PARAMETERS OF B_4C + ZrO_2 COMPOSITES VIA ARTIFICIAL NEURAL NETWORKS METHOD

S. Hartomacıoğlu. PhD.[1], H.O.Gülsoy. PhD.[2], B. Bakırcıoğlu Ms.C.[3]
Department of Mechanical Engineering – Marmara University, Turkey [1]
Department of Metallurgy and Materials Engineering– Marmara University, Turkey [2]
Department of Mechatronics, Selcuk University, Turkey[3]
selimh@marmara.edu.tr

Abstract: *In this study, the effect of production parameters of B_4C + ZrO_2 composites on density was modelled by using Artificial Neural Network (ANN). The composites were produced by using powder injection molding method (PIM). In the sintering stage, pressureless sintering method under argon atmosphere was used. As the production parameters, amount of additional (A, wt.%) and sintering temperature (T, ◦C) were defined. The main aim of the study is to obtain the experimental conditions giving maximum density. As a results of this study, the production parameters of hard sintered materials like B_4C + ZrO_2 could be modelled by using ANN method to optimize and predict because the prediction error is blow percentage of 10%. Therefore, the research and development time and cost can be reduced by using this method.*

Keywords: POWDER INJECTION MOLDING, ARTIFICIAL NEURAL NETWORK, MODELING

1. Introduction

In the literature, most of article about sintering of boron carbide is related to fabrication of boron carbide via hot isostatic pressing and hot pressing method. There are several studies in the literature about the pressureless sintering of boron carbide with additive or non-additive. T.K. Roy et al produced boron carbide ceramics with and without additives (C, TiB_2, and ZrO_2) by pressureless sintering method to obtain dense samples for use as neutron absorber in fast breeder reactors in 2006. They investigated the effect of particle size and sintering temperature on density and microstructure. The compacts were fired in the temperature range of 2225-2375 ºC under vacuum [1]. The effect of ZrO_2-3 % Y_20_3 addition on densification, sintering behavior and mechanical properties of B_4C was studied by H.R. Baharvandi et al in 2006. The adding amount of ZrO_2-3 % Y_20_3 was 0-30 wt.% and sintering temperature was between 2050-2150 ºC [2]. In the 2007, the B4C-metal boride composites were derived from B4C/metal oxide mixture by A. Goldstein et al. The green pellets were sintered from room temperature to 2180 ºC under Ar atmosphere via pressureless sintering method. In this study, TiO_2, ZrO_2, V_2O_5, Zr_2O_3, Y_2O_3 and LaO3 were used for addition [3].

In this study, B_4C + ZrO_2 composites based part produced by powder injection molding method were investigated Density properties of the sintered products were evaluated in sintered condition. The production parameters were modelled using artificial neural network method.

2. Materials and Method

Materials

Boron Carbide (B_4C) is an important non-metallic hard material with high melting point (2450 ºC), high hardness (25 to 35 GPa-next only to diamond and cubic boron nitride), high elastic modulus (450 GPa), high flexural strength (350-500 MPa) and low density (2.52 g/cm3) [1, 4]. ZrO2 is the ceramic material with adequate mechanical properties. In this thesis study, commercially available B4C powder (ABSCO Co, UK) was used. Additive powder, ZrO2 Stack, Germany) powders were used. For molding the mixing powders, binder materials and their rates must be defined. The primary required the binder is to allow flow of the particles into the cavity. Paraffin Wax (PW), Carnauba Wax (CW), Polypropylene (PP) and Stearic Acid (SA) were selected for binder system.

Some properties of binder system components are shown in Table 1.

Table 1: *Some properties of the binder system components*

Binder Type	Density (g/cm^3)	Melting Point ^{o}C
Paraffin Wax (MERC)	0.9	90
Carnauba Wax (MERC)	0.97	112
Polypropylene (MERC)	0.89	161
Stearic Acid (MERC)	0.85	73

Method

Powder Injection Molding (PIM) which enables to produce products with high dimensional accuracy in such a way to have excellent, fine grain structure and non-anisotropic mechanical properties [5] is an advanced manufacturing technology. The other words, PIM method is a new technology and uses the shaping advantage of injection molding but it is applicable to metals and ceramics. Complex, precision, and net shape components are produced by PIM method from metal or ceramic powder. In recent years, PIM has established it-self as a cost-effective production technique derived from plastic injection molding, allowing large scale production of complex part [6]. The product produced by PIM is expected to have more homogenous microstructure since hydraulic pressure is filled up uniformly. Also. Fabrication cost could be eliminated significantly by reducing machining and recycling use of feedstock [7].

PIM method has four steps: 1) Preparation of feedstock, 2) Injection of molding, 3) Solvent and thermal debinding, 4) Sintering [8, 9]. The flow chart of PIM method is shown in Figure 1.

The first mold was designed based on Metal Powder Industries Federation (MPIF) standard 50. The mold was shown in Figure 2.

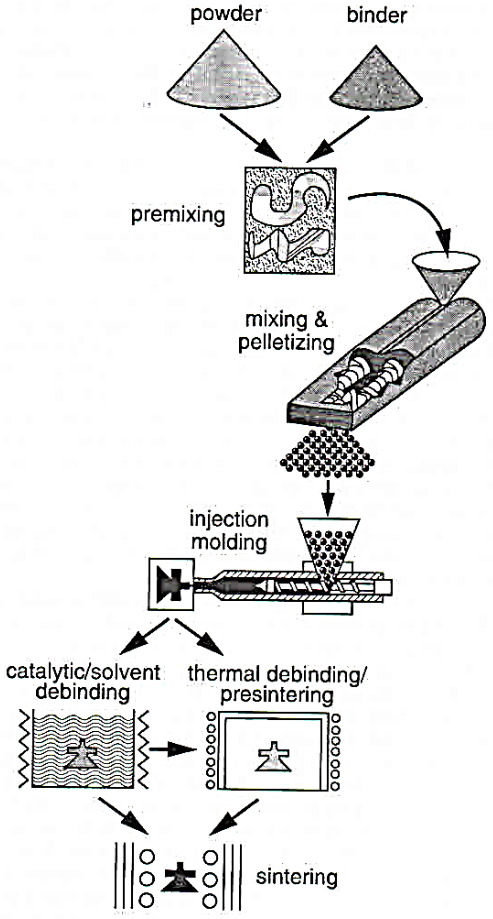

Figure 2 Flow chart of powder injection molding method [7]

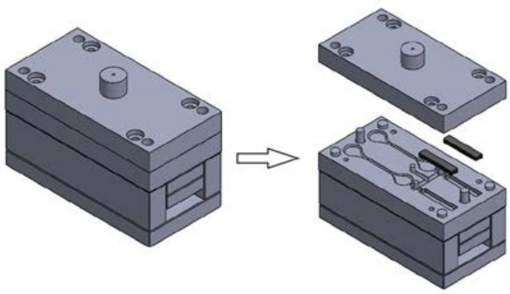

Figure 3 The mold based on MPIF 50 and 59 standard

As a results of pre-experimental studies of PIM methods, the optimal binder materials ratio was defined and listed in Table 2.

Table 2 Mixture ratio of binder system

Binder Types	PW (wt. %)	CW (wt. %))	PP (wt. %)	SA (wt. %)
Mixture Ratio	69	10	20	1

The full factorial experimental design was used as preparation experimental table. The Input parameters and their levels of experimental design was shown in Table 3.

Factors	1	2	3	4	5	6
A: Amount of Ad. (wt.%)	0	2	4	8	12	16
B: Sint. Temp.(˚C)	2000	2100	2200			

The total experimental number according to full factorial experimental design is 18 experiments. The experiment conditions of each experiment number was prepared. The main powder and additive powder was mixed using Turbula Mixer with 3 dimensional motion to be obtained homogenous mixing. The next step, the feedstock was prepared for powder injection molding procedure. In this step, special custom made device was used. The mixed powder and binder system materials was mixed under 130 ◦C temperature and 200 rev./min mixing speed. The granules were obtained by hand and the standard samples were injected by custom made powder injection molding device. In the injection molding device, molding pressure was 15 bar, clapping pressure 10 bar, barrel temperature was 160 ◦C, and Molding speed was 15 sec. From the injected parts, the binder other than Polypropylene was achieved debinding in solvent. In this step, to provide uniform temperature, hot water was circulated continuously around the container of samples with heptane. Thermal debinding process was performed in furnace under Ar atmosphere. After the debinding processes, the samples were sintered using custom made sintering furnace with graphite resistance under Ar atmosphere.

After the sintering, the samples were cut by means of diamond cutting disc. The density of each part was measured by Archimedes Method.

Artificial Neural Network

After the experimental studies, the experimental numerical results were obtained. In the ANN processes, first step the data was normalized between 0 and 1. Then, the data was divided into training data set (75%) and testing data set (25%). After this step, the ANN topology was prepared. In this study, multilayer perceptron (MLP) of ANN structure was used. In this structure, there are there layers: input layer, hidden layer and output layer. In the input layer, the number of processes element (artificial neuron) corresponds to the input parameters of experiments. The output layer processes elements correspond to the output parameters of experiments. In this study, there are 3 artificial neurons in input layer, and there are 1 artificial neuron in output layer. The number of hidden layer neurons was found to be between 1 and 50 by trial and error method under 50 000 epochs. In this study, there are 3 step of ANN procedure, 1) training, 2) testing, and 3) production step. In the training step, optimal ANN structure was obtained using mean square error (MSE) performance criterian. The next step, testing step, the test performance of optimal ANN structure was tested and evaluated. Final step of ANN procedure, the new experimental results were predicted using this optimal ANN structure. The ANN structure of this study was shown in Figure 4.

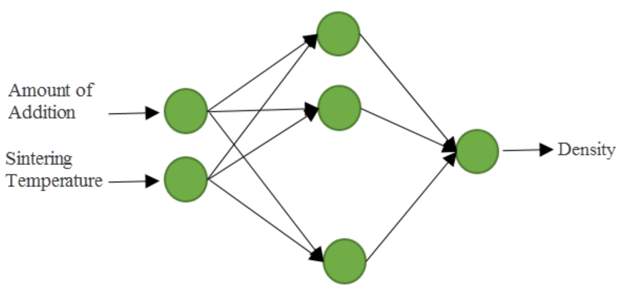

Figure 4 The ANN structure of this study

3. Results and Discussion

After the experimental studies, the experimental results were obtained and the relative density was calculated for each experimental conditions. The experimental results were listed in Table 3.

Table 3 The experimental results

#	A [wt.%]	B [°C]	Y1[%]
1	0	2000	58
2	0	2100	63
3	0	2200	68
4	2	2000	61
5	2	2100	95
6	2	2200	85
7	4	2000	57
8	4	2100	96
9	4	2200	73
10	8	2000	69
11	8	2100	72
12	8	2200	75
13	12	2000	66
14	12	2100	73
15	12	2200	72
16	16	2000	64
17	16	2100	67
18	16	2200	71

After the applying ANN procedure, the training results was shown in Figure 5. The optimal ANN structure was define using this results. In the optimal ANN structure, the number of hidden layer neurons is 20. This value was obtained at 50 000 iterations. Final MSE is 0.46.

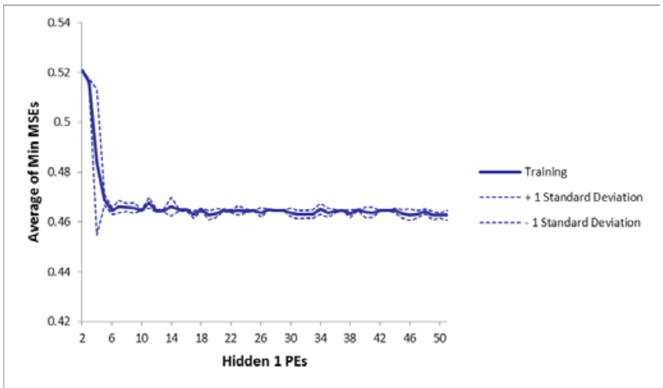

Figure 5: Training results of ANN

In the test steps, the optimal ANN was evaluated by two methods. In the first method, the testing operations was conducted by using training data set, the second method, the testing operations was performed by using test data set. The training data set testing results was shown in Figure 6. In this operations, the correlation coefficient is 0.99, and the percentage error is 0.028%.

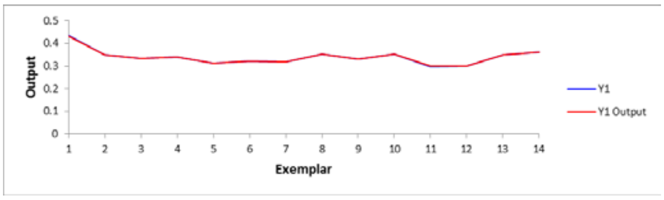

Figure 6 results of training data set testing

The second test operations results were shown in Figure. In this step, the percentage error is %9.36, and correlation coefficient is 0. 95.

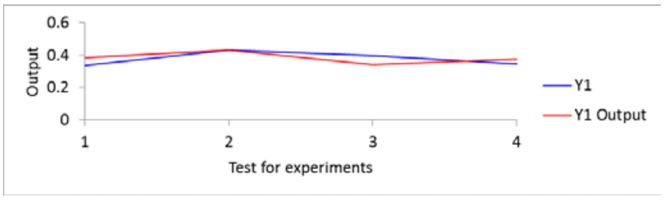

Figure 7 Results of testing data set testing

4. Conclusion

In this study, the production parameters of boron carbide composites were studied and evaluated. Firstly, the powder injection molding method was applied. In this step, the main powder and additive powder was mixed, and then the feedstock was prepared using binder systems. After the granulation, the standard samples were injected. The solvent debinding and thermal debinding processes was applied and then the debinded parts were sintered using different sintering temperature. The densities of sintered samples were measured by using Archimedes Methods, and the theoretical density and relative density values were calculated related formula. After the experimental studies, the optimal ANN structure was obtained using traning, and testing operations. In the testing steps, the percentage error of training data set was 0.029%, and correlation coefficient 0.99, the percentage error of testing data set was 9.36% and correlation coefficient is 0.95. The optimal ANN stricter consist three layer; 1) input layer (3 artificial neurons), 2) hidden layer (20 artificial neurons), and 3) output layers (1 artificial neurons). As a results of this study, the artificial neural networks method was used to modeling the production parameters of hard sintered materials like boron carbide composites.

5. Acknowledgements

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6. References

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