PRODUCTION OF BORON CARBIDE BASED SANDBLASTING NOZZLE by USING LOW PRESSURE POWDER INJECTION MOLDING METHOD and MODELING of PRODUCTION PARAMETERS via ARTIFICIAL NEURAL NETWORK

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Abstract: *In this study boron carbide based sandblasting nozzles were produced by Low Pressure Powder Injection Molding (LPPIM) method, and wear behaviors of the nozzles were examined. The addition powder, addition ratio and sintering temperature were used as input parameters while density, micro hardness and wear rate were used as output parameters in the experimental design. This study consists of 3 steps: 1) production of standard samples and characterization, 2) modeling of proses parameters using Artificial Neural Network (ANN) method, 3) selection of nozzle material and production of nozzle, and testing. As a results of this study, ANN method can be used for modeling of process parameters of powder injection molding since the average value of the prediction error is below 7%, and boron carbide based products can be produced by using LPPIM method.*

Keywords: LOWER PRESSURE POWDER INJECTION MOLDING, ARTIFICIAL NEURAL NETWORK, BORON CARBIDE

1. Introduction

Powder injection molding is a novel process, which combines plastic injection molding and conventional powder metallurgy (PM) technologies. This technique combines the advantages of the plastic injection molding with the material versatility of the traditional powder metallurgy, producing highly complex part of small size, tight tolerance, and low production cost. The process overcomes the shape limitation of traditional powder compaction, the cost of machining, the productivity limits of isostatic pressing and slip casting, and the defect and tolerance limitations of conventional casting. The PIM process is composed of four sequential steps; mixing of the powder and organic binder, injection molding, debinding (binder removal), and sintering [1].

Sandblasting (abrasive blasting, as a surface treatment method) is often applied in the field of Mechanical Engineering, Ship Building Engineering, Chemical Industry, etc. Sandblasting is widely used for surface strengthening, surface modification, surface clearing, and rust removal, surface smoothing or surface roughening, corrosion removal. The blasting could be considered as a technique of abrasive machining; this method is based on the effects generated at the contact of the abrasive particles transported by means of the compressed air jet with the workpiece surface. Sandblasting nozzle is the most critical component and worn by repeated impact of the abrasive particle. The sandblasting operation is shown in Figure 1.

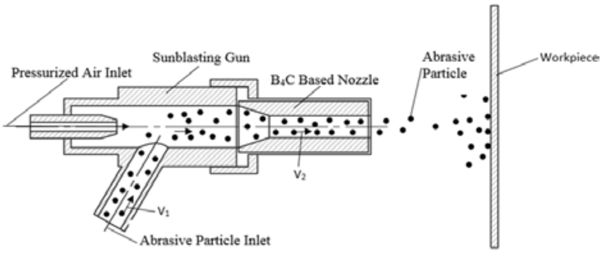

Fig. 1 The working principle of sandblasting operation

The literature review carried out in detail on the subject indicated that, B_4C nozzles are produced by post-hot pressing (HP) and hot isostatic pressing (HIP) techniques [1-5]. These techniques are not economical and not suitable for mass production. The production of B_4C nozzles will become fast and economic by the PIM method. As a result, in the production of B_4C based blast nozzle, aim is to enhance wear resistance and reduce the cost. For enhance of wear resistance and reducing the cost of production B_4C nozzle, the additive materials (SiC, C, TiC, Cu, CrB_2, etc.) were used [2-19].

In this study, B_4C + SiC / Y_2O_3 / TiB_2 composites based sandblast nozzles produced by LPPIM method were investigated and the wear properties of the nozzle materials were examined using sandblasting cabinet testing. Metallographic techniques were employed to sintered sandblast nozzles samples to investigate the sintering behaviors. Density, hardness and erosive wear properties of the sintered products were evaluated in sintered condition. Abrasive air-jet nozzles made of boron carbide with high relative density and excellent wear resistance provides a longer life compared with those made of other materials.

2. Materials and Method

In this study, commercially available B_4C powder (ABSCI Co, UK for base material and SiC, TiB_2 and Y_2O_3 powders (H.C. Stack, Germany) were used for additive powders. Some properties of base powder and additive powders were listed in Table 1.

Table 1: *Some properties of the main powder and additive powders*

Powders	Manufacturer	Average Grain Size	Powder Shape
B_4C	Absco Co.	D_{50}: 14 µm , %98,19 B_4C	Angular
SiC	Almatis Co.	D_{50}: 1.1 µm	Angular
TiB_2	H.C. Stack	D_{50}: 2 µm	Angular
Y_2O_3	H.C. Stack	D_{50}: 1.7 µm	Angular

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 2.

Table 2: *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

Firstly, amount of additive was adjusted and each mixture was blended in a Turbula mixer for 1 hour. The feedstock was prepared using binder system and blended powders by hand at 175 ºC. The powder loading in this mixture was 55 vol%. The feedstocks were injected at 10 bar custom made vertical injection molding machine to produce samples and sandblasting nozzles. In the injection molding step, barrel temperature was 140 ºC, the mold temperature 35-40 ºC, and cycle time was 15 second. The sandblast nozzle design is shown in Figure 2. After injection molding step, solvent and thermal debinding process was performed. In the solvent debinding step, the products were placed into heptane at 70 ºC for 8 hours. Thermal debinding process was performed under Argon atmosphere using debinding furnace at different temperature range. After debinding process and pre-sintering process, the sintering process was performed under Argon atmosphere at 2000 ºC, 2100 ºC and 2200 ºC using special designed furnace with graphite resistant. The special designed high temperature furnace is shown in Figure 3. Finally, the cooling stage with based on the furnace's thermal inertias was used.

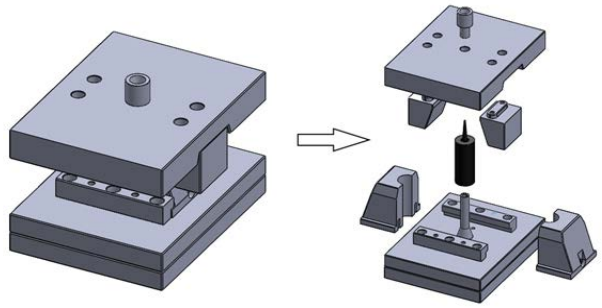

Fig. 2 ***Design of the nozzle mold***

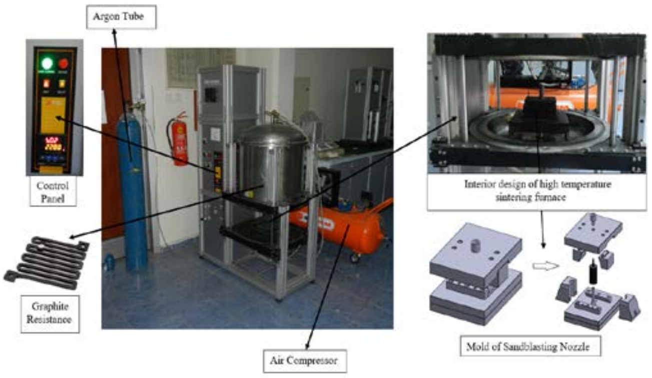

Fig. 3 ***A special designed high temperature sintering furnace***

The densities of the sintered samples and nozzles were measured by using of the Archimedes water-immersion method. The micro-hardness tests were conducted using a Shimadzu-HMV tester under 98.1N load. The wear tests were done using Sandblasting device. In the sand blasting test apparatus, air pressure was set 6 bar, and flow rate is set up 225 m^3/min. SiC powders were used as erodent abrasive and size of particle was between 180-212 µm (80 mesh). The sandblast cabinet test was done for 10 hours, and the weight loss was measured for every hour.

After experimental studies, the results of experimental studies were modelled by using artificial neural networks (ANN) method. In the ANN step, the multilayer perceptron (MLP) was used as ANN topology. MLP consists three layer: 1) input layer, 2) hidden layer, 3) output layer. Each layer consists of neurons named process element. In the Figure 4, view of biological neuron and artificial neuron are shown.

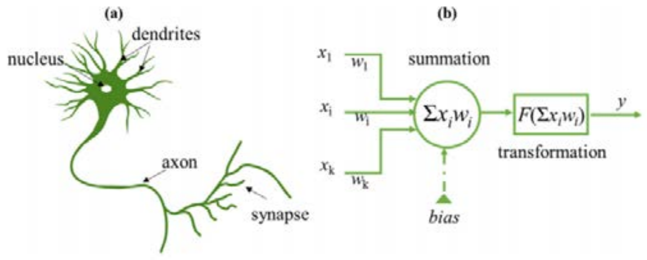

Fig. 4 ***Biological and artificial neuron [20]***

The MLP structure were build and trained in Neurosolutions software environment. In the training step, the mean-square-error (MSE) was used as evaluation performance of structure. In the prediction step, the mean absolute error (MAE) was used as evaluation performance of ANN structure. The neural network structure of the experimental study is shown in Figure 5.

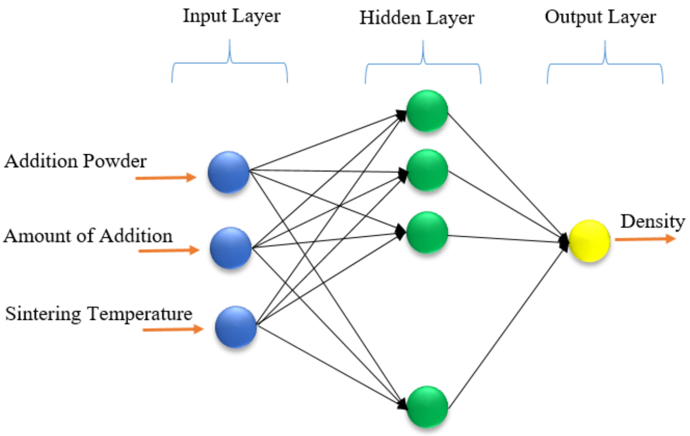

Fig. 5 ***the ANN structure of experimental study***

In the experimental design, full factorial distribution was used. The input variables of the study were amount of additive powder, additive powder, and sintering temperature. The input variables and their levels are listed in Table 2. The output variables of the study were density, micro-hardness and wear rate. Firstly, the full factorial experimental study was performed and then the ANN model was developed using the experimental results. Firstly, the results of experimental study were normalized from 0 to 1, and normalized data set was randomly divided into two groups of 75% training and 25% testing. After training and testing steps of ANN, the optimal ANN structure was determined. Using the ANN structure, the new results were predicts using new input variable levels. In the prediction stage, the values of amount of additional powder and sintering temperature were 0-32wt.% and 2000-2300 ºC, respectively.

Table 3: *Input and output variables of experimental study*

Factors	**1**	**2**	**3**	**4**	**5**	**6**
A: Amount of Additional Powder	0	2	4	8	12	16
B: Additive Powder	TiB_2	Y_2O_3	SiC			
C: Sintering Temperature	2000	2100	2200			

3. Results and Discussion

In the ANN development steps, the effect of change in neuron number of hidden layer on error was shown in Figure 6. Each neural network structure was trained 3 times in 60000 epochs. In the training step, total of 50 different network types were used, and the optimal network structure giving the minimal error was selected from these. The test operation was conducted by using the optimal

ANN structure, and the value of mean absolute error (MAE) was calculated and illustrated in Figure 7. In the optimal ANN structure, the SigmoidAxon was used as transfer function, Momentum (step size:0.1, momentum rate: 0.7) was used as learning rule, neuron number of 22 was defined as hidden layer at 60 000 epoch. As a results of ANN training and testing stage, it is calculated that the average error value is 7.75%.

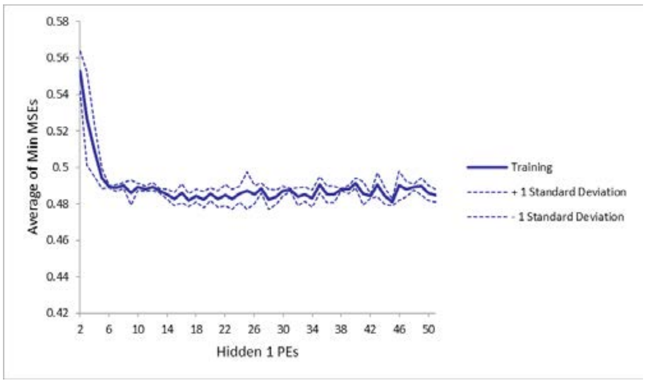

Fig. 6 ***Changing of MSE according to the number of neurons of hidden layer***

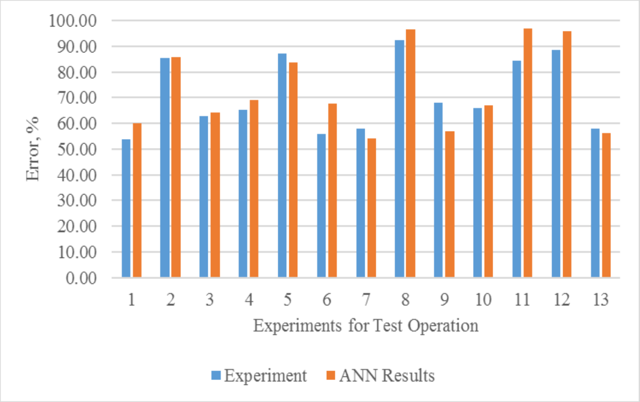

Fig. 7 ***The value of MEA in the test steps of ANN***

New results were predicted using amount of additive powder (0-32wt.%) and sintering temperature (2000 - 2300 ºC) by using the optimal ANN structure. Predicted results were shown in Figure 8, 9 and 10 according to additive powder.

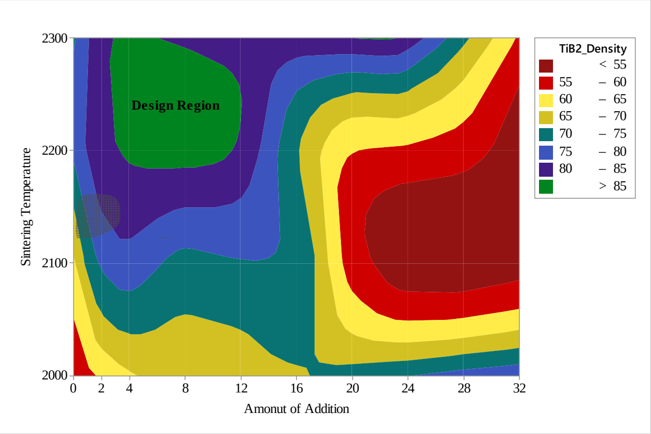

Fig. 8 ***Predicted results of composites with TiB_2 additive***

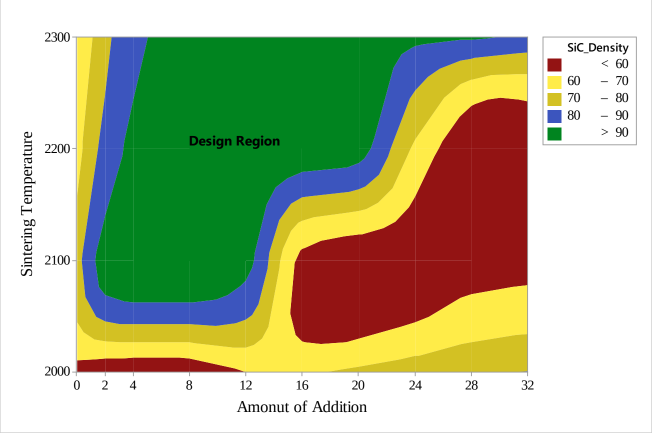

Fig. 9 ***Predicted results of composites with SiC additive***

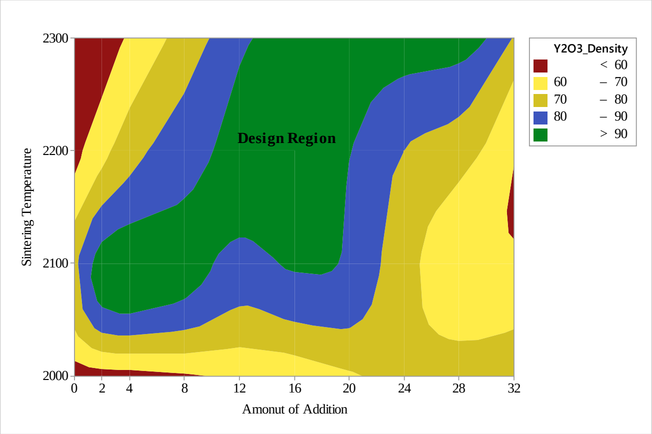

Fig. 10 ***Predicted results of composites with Y_2O_3 additive***

In the Figure 8, 9 and 10, the dark green area was defined as design region for production of B_4C based sandblasting nozzles. The sandblasting nozzle materials were selected from these design areas with high density listed in Table 4 and the nozzles were produced using the optimal experimental conditions.

Table 4: *Selected sandblasting nozzles materials and the properties*

#	Composite	Sint. Temp.	%, Density	Hardness
A0	B_4C	2200 °C	58.00%	8.58
A1	8% TiB_2 + 92% B_4C	2200 °C	90.27%	15.23
A2	8% SiC + 92% B_4C	2200 °C	96.11%	17.21
A3	12% SiC + 88% B_4C	2200 °C	96.64%	18.48
A4	16% SiC + 84% B_4C	2200 °C	96.03%	19.42
A5	4% Y_2O_3 + 96% B_4C	2100 °C	96.93%	14.43
A6	16% Y_2O_3 + 84% B_4C	2200 °C	94.05%	16.95

After the nozzle production, the wear tests were conducted using sandblasting cabinet test equipment (pressure: 6 bar, erodent abrasive: SiC, Time: 10h). The test results were shown in Figure 11.

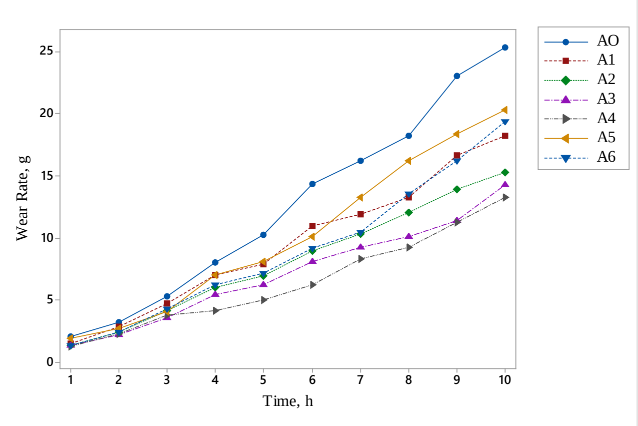

Fig. 11 ***Wear rate of nozzle***

From the Figure 11, the highest amount of wear occurred in the A0 nozzle, the least amount of wear occurred in the A4 nozzle.

4. Conclusion

The main objective of this study is to produce B_4C based sandblasting nozzles via low pressure powder injection molding method (LPPIM). As a results of this study, boron carbide products can be produced by LPPIM method, and ANN method can be used for modeling of production parameter of B4C products. The addition of TiB_2, SiC, and Y_2O_3 on B_4C composite provides significant improvement physical and mechanical properties compare with monolithic B_4C sintered same conditions.

5. Acknowledgements

This work is support by TUBITAK (The Scientific and Technical Research Council of Turkey-Grand: 213M196) and Scientific Research Project Program of Marmara University (Grand: **FEN-K-110117-0019**).

6. References

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