Archives of Materials Science and Engineering

Volume 30
Issue 1
March 2008
Pages 37-40

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Neural network application in simulations of composites Al-Al_2O_3 tribological properties

L.A. Dobrzański *, M. Kremzer, J. Trzaska, A. Włodarczyk-Fligier
Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

Received 22.01.2008; published in revised form 01.03.2008

ABSTRACT

Purpose: The purpose of this paper is application of neural networks in tribological properties simulation of composite materials based on porous ceramic preforms infiltrated by liquid aluminium alloy.

Design/methodology/approach: The material for investigations was manufactured by pressure infiltration method of ceramic porous preforms. The eutectic aluminium alloy EN AC – AlSi12 was use as a matrix while as reinforcement were used ceramic preforms manufactured by sintering of Al_2O_3 Alcoa CL 2500 powder with addition of pore forming agents as carbon fibres Sigrafil C10 M250 UNS manufactured by SGL Carbon Group Company. The wear resistance was measured by the use of device designed in the Institute of Engineering Materials and Biomaterials. The device realize dry friction wear mechanism of reciprocating movement condition. The simulation of load and number of cycles influence on tribological properties was made by the use of neural networks.

Findings: The received results show the possibility of obtaining the new composite materials with required tribological properties moreover those properties can by simulated by the use of neural networks.

Practical implications: The composite materials made by the developed method can find application among the others in automotive industry as the alternative material for elements fabricated from light metal matrix composite material reinforced with ceramic fibers.

Originality/value: Worked out model of neural network can be used as helpful tool to prediction the wear of aluminium matrix composite materials In condition of dry friction.

Keywords: Computational materials science; Composites; Infiltration; Simulation; Neural networks

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

An increased interest is observed in last years in metal matrix composite, mostly light metal based, which have found their applications in many industry branches, among others in the aircraft industry, automotive-, and armaments ones, as well as in electrical engineering and electronics, etc. The metal matrix composite can be reinforced with particles, dispersoids or fibres. However, the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their tribological-, heat- or mechanical properties by selection of the volume fractions, size, and distribution of the reinforcing particles in the matrix [1-3].

Aluminum based composite materials are leading ones in this area, they are fabricated using many methods, including infiltration processes [4,5]. The infiltration of ceramic porous preform by a liquid alloy is a cost-effective method for the manufacture of metal matrix composites and allows to obtain the following technological-organizational profits [6-8]: the possibility of obtaining the composite products of precise shape mapping and the high-quality surface (near net shape), adaptation of the process to the mass scale production, free variability of reinforcing phase and matrix material, high-productivity process with relatively low-cost of production, the possibility of local reinforcement of the product.

The relatively poor wear resistance of aluminium alloys has limited their uses in certain tribological environments. Seizure and wear resistance in aluminium alloys could be substantially improved by incorporating of hard ceramic particulates or fibres (e.g., Al_2O_3, SiC, BN, Ti(C,N) and ZrO_2) [9-12]. Designing of composite materials with advantageous tribological properties is not easy and is connected with analysis of many factors [13,14]:

- chemical composition of reinforcement,
- portion of reinforcement,
- changes of the shape and size of reinforcement.

The artificial neural networks, as a versatile numerical modelling tool, are frequently used for solving the practical problems in so different areas as medicine, economy, physics or engineering applications. A relatively simple development method of the analysed phenomenon model features an important advantage of neural networks, provided the relevant amount of experimental data is collected. The interest in neural networks grows also in the area of materials engineering, and solutions making use of them demonstrate very often better conformance with the modelled reality than the empirical relationships or mathematical models. Their capability to generalize the knowledge for the new data, which was not presented during training, causes that the knowledge of the physical model of the described phenomena is not required [15].

The goal of this work is the application of neural network in simulation of tribological properties of the EN AC - AlSi12 alloy matrix composite materials reinforced with the Al_2O_3 preforms fabricated by sintering of Alcoa CL 2500 powder with addition of pore forming agent, fabricated by the pressure infiltration process.

2. Experimental procedure

The material for investigation was produced by he method of pressure infiltration of porous ceramic frameworks with liquid aluminium alloy. The composites matrix consisted of euthetic alloy EN AC – AlSi12 and as the reinforcement the porous ceramic frameworks consisted of sintered Al_2O_3 particles were used.

Ceramic preforms from Al_2O_3 particles were manufactured by Aloca CL 2500 powder sintering method with addition of pore forming agent in form of carbon fibres Sigrafil C 10 M250 UNS from SGL Carbon Group company. The properties and chemical composition of the used carbon fibres and ceramic powder are shown in Table 1 and 2 respectively.

Manufacturing process of the ceramic preforms comprised:

- preparation of powder and carbon fibres mixture,
- pressing of prepared powder mixture,
- compact sintering.

Table 1.
Properties of Sigrafil C10 M250 UNS carbon fibers [2]

Property	Value
Fiber diameter [µm]	8
Mean fiber length [µm]	135
Fiber density [g/cm^3]	1.75
Tensile strength [GPa]	2.5
Young's modulus [GPa]	26
Carbon content [%]	>95

The addition of the carbon fibres was 30, 40 and 50 % of weight. Into Al_2O_3 suspension were added the addition of anti-forming agent of the set of carbon fibres Dolapix CE 64 of Company Zschimmer und Schwarz GmbH Company, eliminating their electrostatic interactions. In order to make pressing easier, 1% polyvinyl alcohol Moviol 18-8 solvable in water was added. The ceramic powder and carbon fibres mixtures were uniaxially pressed in the hydraulic press "Nelke" in steel mold with the inside diameter of 30mm. The maximum pressure was 100 MPa and pressing time was 15s. Compacts were sintered in "Gero" pipe furnace in air atmosphere (20 l/min). The temperature during the sintering process was ensuring the carbon fibres degradation (heating by 10h in temperature 800 ºC) and Al_2O_3 powder sintering in temperature of 1500 ºC by 2h. The porosity of the ceramic performs depends on the carbon fibres content 69% at 30% of carbon fibres addition, 75% at 40% of carbon fibres addition and 80% at 50% of carbon fibres addition, respectively.

The internal surfaces of ceramic preforms were coated with nickel in order to improve the Al_2O_3 wettability by the liquid aluminium alloy. Solutions containing metallic palladium were used for activation of the ceramics surface. Reagents were pumped through preforms to cover their internal surfaces on especially designed device.

Uncoated and coated by nickel ceramic preforms were heated in furnace up to temperature of 800 ºC. Covered by graphite form was warmed up to 450 ºC (maximal temperature of the press plates) and then fulfilled with preform and liquid alloy EN AC – AlSi12 with temperature of 800 ºC. The whole was covered by the stamp and placed in hydraulic plate press Fontune TP 400. The maximum infiltration pressure was 100 MPa and load was 120 s. After solidification obtained materials were removed from the form and cool down under pressured air stream.

Table 2.
Properties and chemical composition of Alcoa CL 2500 powder

Diameter D50[µm]	Density [g/cm^3]	Mean mass concentration of elements, wt.%						
		Al_2O_3	Na_2O	Fe_2O_3	SiO_2	CaO	B_2O_3	Others
1.80	3.98	99.80	0.05	0.02	0.01	0.01	0.01	0.10

The wear resistance was measured by the use of device designed in the Institute of Engineering Materials and Biomaterials. The device realize dry friction wear mechanism of reciprocating movement condition. The samples preparation for examinations consisted of grinding by the use of abrasive paper with grit # 1200 to obtain flat and smooth surface. On samples prepared in this way there were made investigations with the steel ball 8.7 mm diameter as counter-sample. Investigations were made with different number of cycles 1000, 2000, 3000, 4000, 5000, respectively: 24, 48, 72, 96 and 120 m, friction distance and under different load 2.5, 5, 7.5, 10 N. Samples after examinations were rinsed in ultrasonic washer to clean its surface, and then the degree of wear was established on the base of geometrical measurements of wear track and calculation of its volume. The volume loss as the indicator of absolute wear is used when the mass loss is too small and difficult to estimate.

To evaluate the correlation between the amount of reinforcement phase, load, number of cycles (friction distance) and the abrasive wear expressed by the volume of wear track artificial neural network were used. Models of neural network and their numerical simulation was made in Statistica Neural Networks version 4.0F. The task of neural network development require to determine the following quantities: type of neural network, structure of neural network, function of error, the type and form of the activation function, function of post synaptic potential (PSP), neural network training technique and parameters, variable scaling procedure.

Artificial neural networks allow building the relation between examined quantities without define the mathematical description of analyzed problem. However the main significance has the preparation of representative set of experimental data.

Worked out, on the base of own experimental results, set of data was randomly split in three sub-sets: training set, validation set, test set. Data from training set were used to determine the weight of each member during network while learning, data from validation set - to evaluate quality of network during training process. Residual part of data (test set) was used for evaluation of the established model after the training phase.

3. Experimental results and their discussion

As a result of tribological measurements there were estimated the wear resistance in the condition of dry friction of composite materials. For modelling abrasive wear of composite materials reinforced by ceramic preforms artificial neural networks were used calculating the volume of wear loss. As input there was used our variable: portion of reinforcement, load, number of cycles and bi-stated nominal variable determining occurring of nickel coating on the surface of ceramic performs. The number of cases in training validation, test set is equal 900, 150, 150, respectively.

Pre-analysis of obtained results allows to choice for further calculations the MLP-type neural network. In the next step of neuron model modeling it was concentrated onto the optimization of neuron number in hidden layer, method and parameters of network training, error function and activation function. The influence of neural number in hidden layer on the error is presented in Fig. 1. The best coefficients assumed for the neural network were obtained for network with a structure 4-8-1 with logistic activation function in hidden layer trained by Levenberg-Marqardt method by 1500 epochs. Values of quality assessment coefficients are presented in Table 3. Simulation of the load and cycles number influence onto the wear of chosen composite materials is presented in Fig. 2.

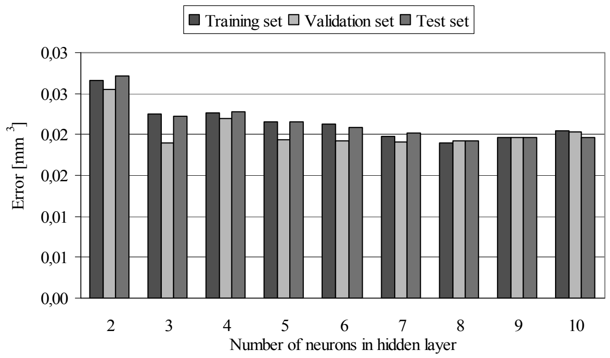

Fig. 1. The influence of neuron number in hidden layer on the network error

4. Conclusions

Worked out model of neural networks allow to evaluated the abrasive wear of examined materials depending onto the portion of ceramic phase, friction distance, load and are fully adequate to obtained results of experimental data. Application of worked out calculation model allow to the simulation of the influence of reinforcement, load, friction distance on abrasive wear of manufactured composite materials.

Table 3.
Characteristic of chosen neural network worked out to evaluate abrasive wear of composite materials

Network type	Structure of network	Training parameters	Data set			Quality assessment coefficients for neural networks
			Training	Validation	Test	
MLP	4-8-1	LM1500	0.0190	0.0192	0.0193	Mean error, mm^3
			0.1168	0.1201	0.1191	Ratio of standard deviations
			0.99	0.99	0.99	Pearson’s correlation coefficient

LM - Levenberg-Marquardt training method of neural network

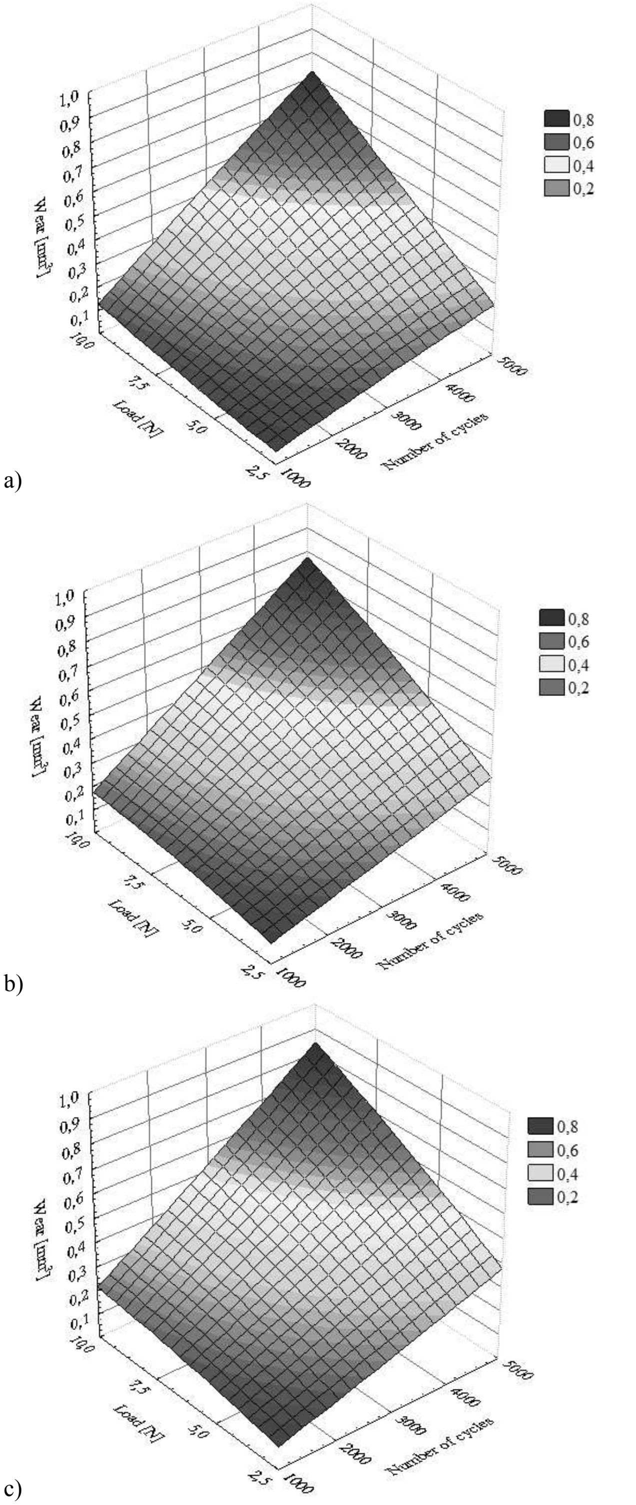

Fig. 2. Simulation of the load and number of cycles influence onto the abrasive wear of chosen composite materials with volumetric uncoated reinforcement. a) 31%, b) 25% and c) 20% of ceramic phase content

References

[1] L.A. Dobrzański, A. Włodarczyk, M. Adamiak, Structure, properties and corrosion resistance of PM composite materials based on EN AW-2124 aluminum alloy reinforced with the Al_2O_3 ceramic particles, Journal of Materials Processing Technology, 162-163 (2005) 27-32

[2] L.A. Dobrzański, A. Włodarczyk, M. Adamiak, Aluminum alloy AlCu4Mg1 matrix composite materials reinforced with ceramic particles, Proceedings of the 12th Scientific International Conference „Achievements in Mechanical and Materials Engineering”, AMME 2003, Gliwice – Zakopane, 2003, 297-300 (in Polish).

[3] A. Włodarczyk-Fligier, L.A. Dobrzański, M. Adamiak, Influence of the heat treatment on properties and corrosion resistance of Al-composite, Journal of Achievements in Materials and Manufacturing Engineering 21/1 (2007), 55-58.

[4] A. Mattern, B. Huchler, D. Staudenecker, R. Oberacker, A. Nagel, M.J. Hofmann, Preparation of interpenetrating ceramic-metal composites, Journal of the European Ceramic Society 24 (2004) 3399-3408

[5] A. Elwahed, M. Assar, Fabrication of metal matrix composite by infiltration process-part 2: experimental study, Journal of Materials Processing Technology 86 (1999) 152-158

[6] J. Sobczak, Metal Composites, Cracow – Warsaw, 2001 (in Polish)

[7] L.A. Dobrzański, M. Kremzer, A.J. Nowak, A. Nagel Composite materials based on porous ceramic perform infiltrated by aluminium alloy, Journal of Achievements in Materials and Manufacturing Engineering, 20 (2007) 95-98

[8] L.A. Dobrzański, M. Kremzer, A. Nagel, B. Huchler Fabrication of ceramic preforms based on Al_2O_3 CL 2500 powder, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 71-74.

[9] L.A. Dobrzański, M. Kremzer, A. Nagel, Aluminium EN AC - AlSi12 alloy matrix composite materials reinforced by Al_2O_3 porous performs, Archives of Materials Science and Engineering 28/10 (2007) 593-596

[10] C.K. Fang, C.C. Huang, T.H. Chuang, Synergistic Effects of wear and corrosion for Al_2O_3 particulate reinforced 6061 aluminium matrix composites, Metallurgical and Materials Transactions 30A (1999) 643-646.

[11] S. Basavarajappa, G. Chandramochan, Dry sliding wera behavior of metal matrix composites: a statistical approach, Journal of Materials Engineering and Performance 15/6 (2006) 656-659.

[12] A. Daoud, T. El-Bitar, A. Abd El-Azim, Tensile and wear properties of rolled Al5Mg-Al_2O_3 or C particulate composites, Journal of Materials Engineering and Performance 12/4 (2003) 390-397.

[13] A. Posmyk, Modeling of tribological properties of aluminium matrix composite materials, Materials Engineering 2 (2006) 69-74 (In Polish).

[14] Y. Sahin, M. Acilar, Production and properties of SiCp-reinforced aluminium alloy composites, Composites A34 (2003) 709-718.

[15] Biocybernetics and biomedical engineering, ed. M. Nałęcz, vol. 6 Neural networks, ed. W Duch, J Korbicz, L. Rutkowski, R. Tadeusiewicz, EXIT Press, Warsaw 2000 (in Polish).