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Modeling analysis of chrome carbide (Cr_3C_2) coating on parts of combustion chamber of a SI engine

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ABSTRACT

In this study; piston, exhaust, and input valves of a gasoline engine were coated in 300 μm thickness with Cr_3C_2 by using the plasma spray coating method. The performance and emission values obtained from coated and uncoated engines were loaded on Artificial Neural Network (ANN) and estimated values were produced for every speed. Thus mathematical modeling of coated and uncoated (standard) engines was performed by using ANN. It was aimed to reduce the experiment repetitions and to decrease the experiment costs. The results obtained from the experiments were loaded on ANN and the values of the engines at all speeds were estimated. Results obtained from the tests were compared with those obtained from ANN and they were observed to be compatible. It was also observed that, with thermal barrier coating, specific fuel consumption (SFC), hydrocarbon (HC) and carbon monoxide (CO) values of the gasoline engine decreased; but NO_x and exhaust gas temperature (EGT) increased. Furthermore, it was determined that results obtained through mathematical modeling reduced the number of test repetitions. Therefore, it was understood that time, fuel and labor could be saved in this way.

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1. Introduction

Energy need per capita in the world has a continuous tendency to increase. The increase in the energy demands also increases the dependency on fossil fuels especially petroleum and natural gas. As the years pass, the needs of the automobile buyers have considerably changed. In addition to comfort and design aspects, subjects such as fuel consumption and efficiency have become one of the most important matters of automobile buyers and sellers. One of its reasons is the fuel efficiency standards which have become strict gradually. According to the current European emission regulations, highway tax rates of the vehicle are related to the exhaust emissions. The truth about the limited oil reserves shows that more fuel saving is an indispensable requirement [1]. In internal combustion engines, heat loss occurs in the engine due to the cooling system elements [2]. In order to minimize such loss in the engines, one of the methods applied is thermal barrier coating (TBC). By TBC, it is aimed to increase combustion efficiency, to enhance emissions and to reduce fuel consumption. TBC methods generally depend on the principle under which the coating material is made as molten or semi-molten and then it is sprayed on the surface [3]. It has been specified in numerous studies that generally performance and exhaust emission values have improved in TBC -applied internal combustion engines. Ciniviz et al. determined that there was a strong relationship between the insulation levels and performance and the emission values. As a result of their coating experiments, they observed that as the insulation level increased, the change level in the parameters measured also increased [4]. In their study, Sivakumar et al. investigated the effect of performance and emissions of the engine by coating the pistons of an internal combustion engine with stabilized zirconium and determined a decrease of 2.7% in CO emission and a decrease of 35.27% in HC emissions [5]. Çırak et al. examined the effects of TBC on the emissions by using ANN in diesel engines in the experiments and determined that there was generally an increase in NO_x emission and a decrease in HC, CO and smoke emissions as a result of increasing the insulation level in a normal engine (SE). As a result of a coated engine (CE) application, it was concluded that the changes observed in the emission parameters occurred mainly due to the increase in the in-cylinder gas temperatures [6]. However, measuring and repeating performance and emissions values of internal combustion engines at all revolutions is a very costly and time-consuming process. It is possible to obtain estimated values of engines at all revolutions through forming mathematical models of engines by using ANNs

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that can generate estimated values through teaching. ANN is an advanced data processing system which is composed of a number of simple process elements operating collaterally and can self-regulate through learning [7–10]. All the test results obtained before or after coating process were aimed to actualize learning in ANN. Once learning was actualized in ANN, it was possible to access very easily the values of internal combustion engines at all revolutions in computer environment. In addition, a model was designed to view these obtained values more visually in computer environment. The model is a summary or representative of an actual event. The model is not an exact copy of a system or process; but it can replace the process provided that it contains certain details [11]. In our study, YSA MATLAB GUI was used in order to form mathematical models. YSA MATLAB GUI is a high-performance application software and programming language. It is a graphical program interface that enables interaction with users and run an operation or a program through the usage of objects contained. Real engine conditions cannot be created in even very well designed laboratory test conditions; because chemical and mechanical events occurring in the combustion chamber are very complex. This is why it was important for us to conduct our experiments in real engines. The purpose of this study is to carry out tests at certain rpm values in the actual environment in a diesel engine and then to operate these data in ANN program. Thus, we can access all emission and performance data of the engine without carrying out the test for each desired rpm. Thus, test costs would reduce and test results for each desired rpm will be acquired.

2. Materials and methods

2.1. Plasma spray coating method applied in the experimental study

Plasma spray is actually a type of thermal spray method. The coating material is fed in hot plasma flame, heated until it has semi-plastic state and rapidly sprayed towards the substrate. As a result of collision, the hot particles adhere to the substrate and then to each other and they form the coating layer [11]. Plasma has two major important advantages. One of them is to obtain high temperature that can melt all the known materials and second one is to provide better heat transfer to the other materials [12]. Fig. 1 illustrates section of the plasma spray gun and plasma formation.

Ceramic coatings performed by using plasma spray method have better wear and erosion resistance than various metals and they are widely used in internal combustion engines and in erosion and wear resistant applications. Plasma spray process can also be performed under vacuum or low pressure. Since plasma formed during the plasma spray process has high temperatures, it enables usage of materials having very high melting temperature as coating powder.

Table 1
Chromium carbide's physical and mechanical properties [15,16].

Density (g cm^{-3})	6.65–6.68
Young's module (GPa)	373
Compressive strength (GPa)	4.138
Molecular mass (g mol^{-1})	180.01
Boiling point (°C)	3800
Melting point (°C) (Cr_3C_2)	1890
Thermal expansion coefficient α (10^{-6} °C^{-1})	11.2
Thermal conductivity (W (m K)$^{-1}$)	189.77
Linear thermal expansion coefficient α (10^{-6} °K^{-1})	11.10
Hardness-VH (kg mm^{-2})	1834

2.2. Powder material used in coating process in the experimental study (chromium carbides)

Chromium carbide is a ceramic compound that can be present in three chemical compositions. These compositions are Cr_3C_2, Cr_7C_3, and $Cr_{23}C_6$. Cr_3C_2 is the most stable one of these three compositions and it has an orthorhombic crystal structure and a hardness of 23.5 GPa Vickers [13,14]. Due to its properties, it can be added to the metal alloys as an additive. When chromium carbide is coated on the surface of a metal, it both provides wear and corrosion resistance on the surface and maintains this property at high temperatures. For such coating applications, the hardest and generally most used composition is Cr_3C_2. Table 1 illustrates mechanical and chemical properties of chromium carbide.

Chromium carbide is used as a thermal spraying material in the locations where it is required to have the surface of the metal materials hard and resistant against corrosion and wear.

2.3. Artificial neural networks used in this study

ANNs are computer software that imitate the neural networks of human brain; interconnect by means of weighted connections; and are capable of deriving, discovering, and generating new information by means of learning by generalizing through examples. ANNs perform a number of functions such as prediction, classification,

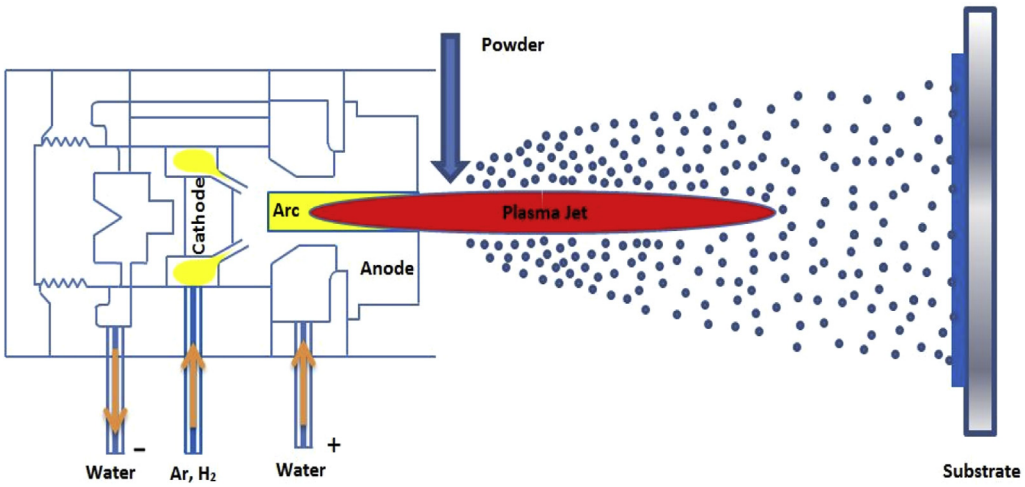

Fig. 1. Plasma spraying system.

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